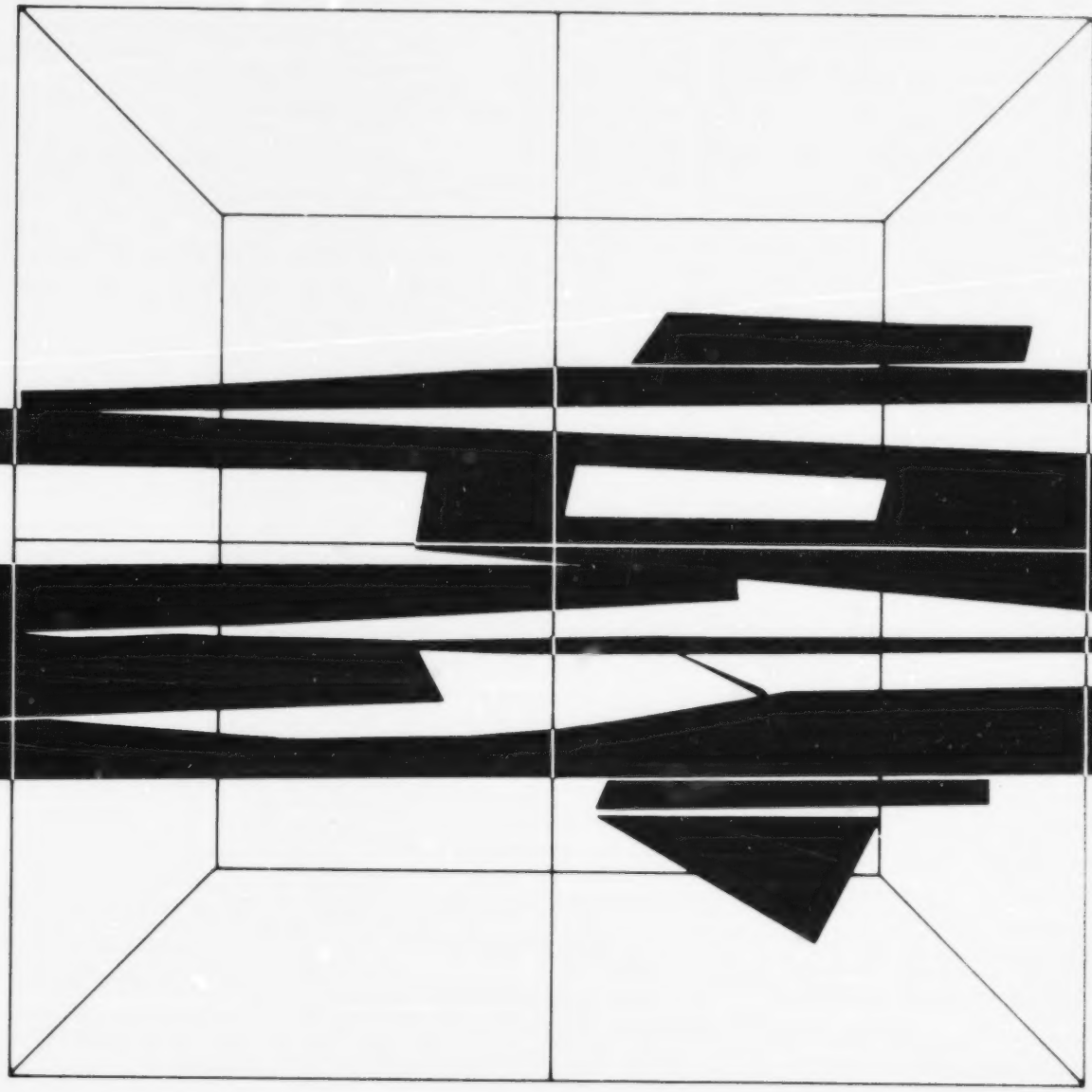
Kitchener Landfill Gas Utilization Project

Report EPS 3 UP 4
August 1987



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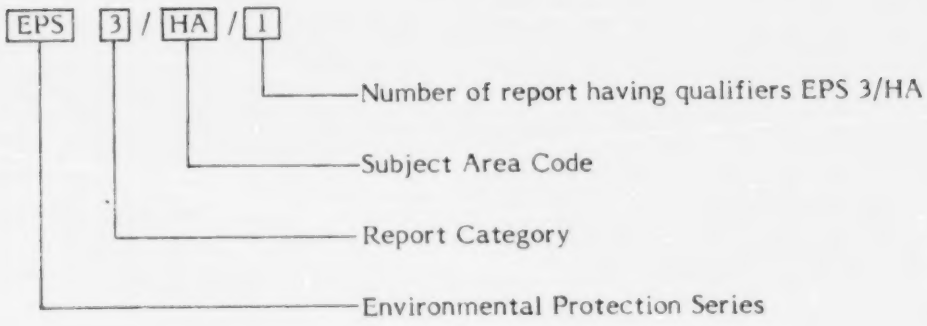

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KITCHENER LANDFILL GAS UTILIZATION PROJECT

by

Conestoga-Rovers & Associates Ltd.
Waterloo, Ontario

for the

Technology Development and Technical Services Branch
Environmental Protection
Conservation and Protection
Environment Canada

This project was conducted under the Development and Demonstration of Resource and Energy Conservation Technology (DRECT) Program

Report EPS 3/UP/4
August 1987

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ABSTRACT

In October 1981, the Regional Municipality of Waterloo presented a proposal and application to Environment Canada for funding under the DRECT program for a proposed landfill gas extraction and utilization system at the Kitchener landfill site in Kitchener, Ontario. The project was to be undertaken in two phases and to be completed by the end of March 1984.

As originally proposed, Phase I consisted of: the design and installation of a pumphouse and pumping equipment; fifteen southern sector wells; gas transmission lines; and the conversion of one boiler at Bestpipe for acceptance of landfill gas as a fuel supply. The completion of Phase I was delayed from the original schedule because of low methane concentrations and operational difficulties upon start-up.

Following Phase I, Conestoga-Rovers & Associates (CRA) undertook, at their own expense, an extensive investigation of the landfill gas utilization system to determine the cause of the operational difficulties which persisted throughout the initial phase of the project. Based on the findings of this investigation a Phase I Optimization Plan was carried out and a modified Phase II plan was recommended.

This report presents a comprehensive review of the project which was completed in February 1985.

RÉSUMÉ

En octobre 1981, la municipalité régionale de Waterloo présentait à Environnement Canada une demande de financement d'une installation de captage et d'utilisation des gaz d'une décharge contrôlée située à Kitchener en Ontario, dans le cadre du Programme de création et de démonstration de techniques de conservation des ressources et de l'énergie. L'installation devait être réalisée en deux phases et devait être terminée pour la fin de mars 1984.

Dans la demande originale, la phase I comportait les étapes suivantes: la conception et l'installation d'une station de pompage et de l'équipement nécessaire; l'aménagement de quinze puits dans la partie sud de la décharge; l'installation de conduites de transport du gaz; et la transformation d'une chaudière de l'usine Bestpipe en vue d'une alimentation en gaz de résidus (ou biogaz). Le déroulement de la phase I a été retardé à cause de la faible teneur en méthane des gaz captés et de difficultés d'exploitation au moment de la mise en marche.

À la suite de la phase I, Conestoga-Rovers & Associates Ltd. (CRA) a entrepris à ses frais une étude poussée sur l'installation de captage et d'utilisation du gas de résidus afin de trouver la cause des ennuis qui ont persisté pendant la phase initiale de l'exploitation. À la suite de cette étude, un plan d'optimisation de la phase I a été réalisé et une modification de la phase II a été recommandée.

Le présent rapport fournit une description complète de l'installation, achevée en février 1985, et de son exploitation.

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1 PHASE I - LANDFILL GAS AND UTILIZATION SYSTEM

1.1 Site and Project Background

The Kitchener landfill site is located in Kitchener, Ontario (Figure 1). The landfill area is about 30 ha (75 acres) and was operated by the city of Kitchener from 1958 to 1974 and by the Regional Municipality of Waterloo from 1974 to 1978, after which time it was closed. During its operation, approximately two million tonnes of domestic refuse were disposed of at the site.

The landfill is divided into north and south sections by a hydroelectric power corridor right-of-way (Figure 2). The northern portion of the site was filled from 1958 to 1972 and comprises an area of about 20 ha (50 acres) with a disposal waste depth of approximately forty-three metres. The lower twelve metres of disposal wastes are primarily domestic refuse and the remaining thirty-one metres are relatively inert material and construction rubble. The southern sector of the landfill site covers an area of 10 ha (25 acres) and has a refuse depth of approximately twelve metres. This portion of the site was operated from 1972 to 1978 and received primarily domestic wastes.

The upper overburden surrounding the site consists of a silty sand material. Landfill gas migration laterally away from the site has been a major concern over the past decade because of the relatively high permeability of this material. The Regional Municipality of Waterloo has installed a number of landfill gas control systems at the site to alleviate this problem. Another solution was the installation of a landfill gas recovery and utilization system on site which would utilize the gas and help alleviate some of the gas migration problems.

The Region and the Ontario Ministry of Energy contracted Conestoga-Rovers and Associates Ltd. (CRA) to conduct pumping tests at the landfill site. These tests were designed to determine the quantity composition and the technical feasibility of recovering landfill gas at the site to be used as fuel for the boilers at Bestpipe. The results of the initial pumping tests carried out in 1981 indicated that:

1. there was sufficient quantity and quality of recoverable landfill gas at the Kitchener landfill site to supply Bestpipe with unprocessed landfill gas for use as fuel in their industrial boilers (approximately 2.8×10^4 m^3/d of 13.13 MJ/m^3 landfill gas);
2. a landfill gas recovery rate of 1.1×10^{-2} $m^3/kg \cdot yr$ could be used as the design gas recovery rate for the landfill site; this gas recovery rate is equivalent to 3.8×10^{-3} $m^3/kg \cdot yr$ (methane per kilogram of refuse per year);
3. the gas well should be sized for a maximum recovery rate of 11.8 L/s;

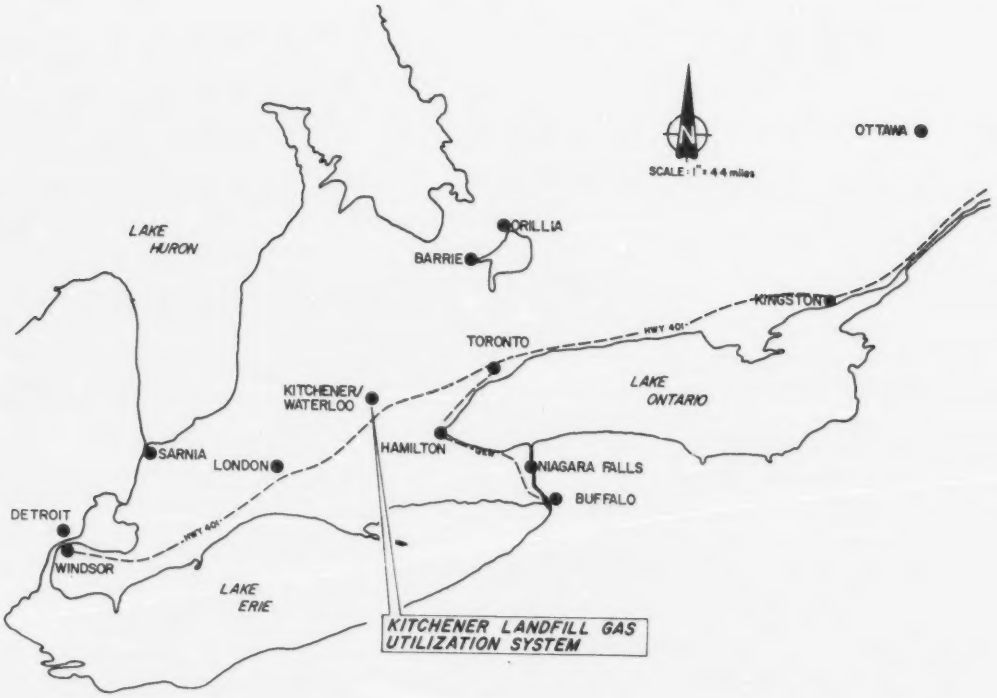


FIGURE 1 REGIONAL SETTING

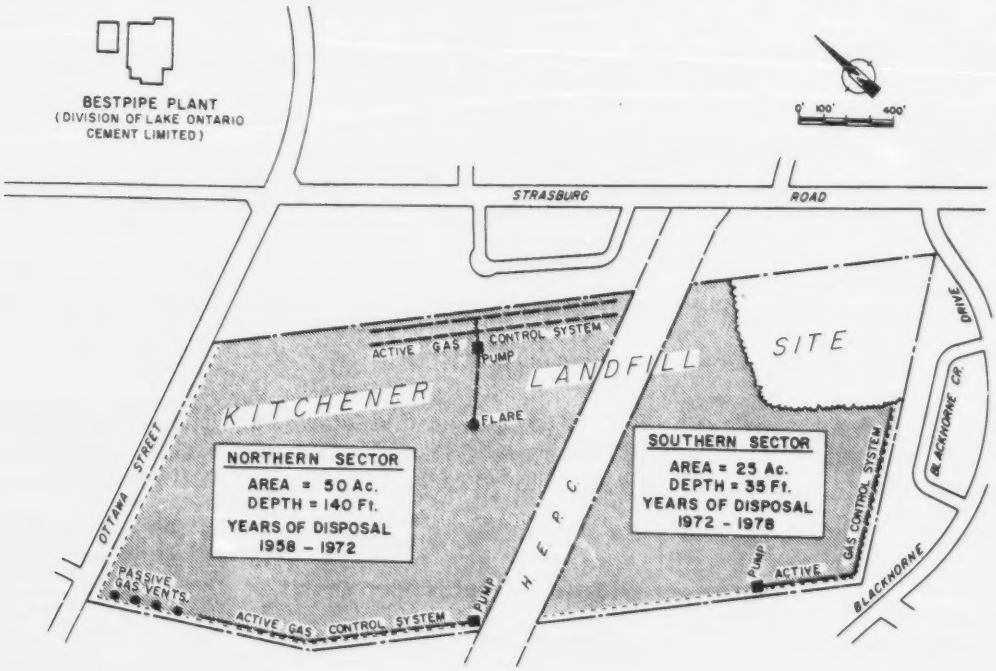


FIGURE 2 SITE CHARACTERISTICS

4. gas recovery should be placed primarily on the southern sector of the landfill site due to the more recent refuse placement and ease of access; and

5. given the time and placement of the refuse, it could be expected that good quality gas (f30% methane) would be generated for ten more years.

It was decided to proceed with the design and construction of a landfill gas system to fuel industrial boilers at Bestpipe, given the test results and receipt of the DRECT grant from Environment Canada.

The project proceeded in two phases. Phase I was designed to provide enough fuel for one industrial boiler at the Bestpipe plant. Phase II was amended to proceed in two parts after studying the Phase I results. Phase II, Part A, consisted of the installation of ten additional gas extraction wells and a pumping test at the combined peak flow required to operate two boilers at Bestpipe. Phase II, Part B, was to include mechanical additions to the existing gas pumping system to provide enough fuel for the second boiler at Bestpipe to operate on landfill gas. Phase II, Part B, was not undertaken after studying the test results of Part A.

1.2 System Components

The landfill gas recovery and utilization system includes four basic components:

1) a gas recovery system;
2) a gas pumping system;
3) a gas transmission system; and
4) a gas utilization system.

A schematic illustration of the landfill gas system is presented in Figure 3.

1.2.1 Gas Recovery System. The gas recovery system includes the gas recovery wells, and the lateral and header gas collection pipe systems.

Fifteen wells were installed and connected by lateral lines to a header line on the western side of the landfill site. The header line leads to the pumphouse and processing system.

Figures 4 to 11 show details of the various gas system components, as constructed. These figures include: well installation, negative pressure water drains, lateral connections to existing wells, bedding details, in-line valve installations, manhole casting and cover construction, and steel service riser construction connecting the collection header to the pumphouse.

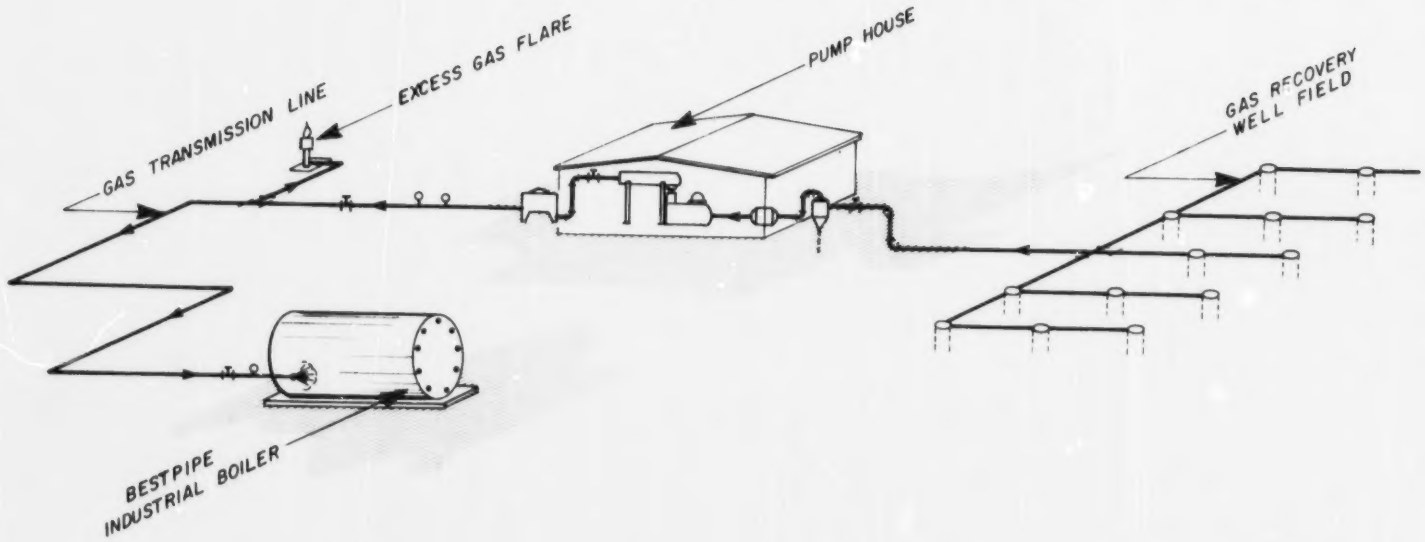


FIGURE 3 SCHEMATIC OF GAS UTILIZATION SYSTEM

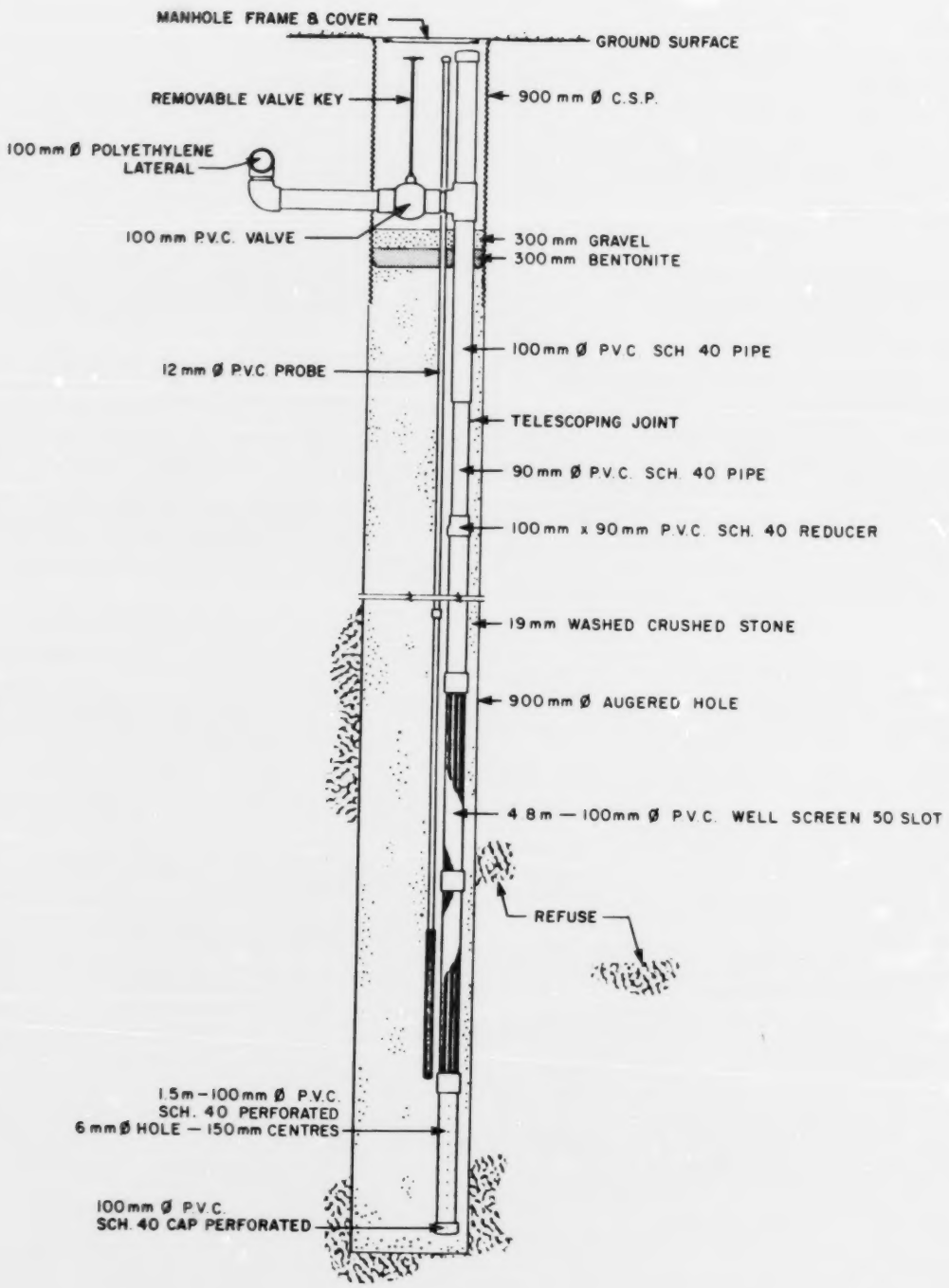

MANHOLE FRAME & COVER
GROUND SURFACE
REMOVABLE VALVE KEY
900 mm Ø C.S.P.
100 mm Ø POLYETHYLENE LATERAL
100 mm P.V.C. VALVE
300 mm GRAVEL
300 mm BENTONITE
100mm Ø P.V.C SCH 40 PIPE
12 mm Ø P.V.C PROBE
TELESCOPING JOINT
90 mm Ø P.V.C. SCH. 40 PIPE
100mm x 90mm P.V.C. SCH. 40 REDUCER
19mm WASHED CRUSHED STONE
900mm Ø AUGERED HOLE
4.8m — 100mm Ø P.V.C. WELL SCREEN 50 SLOT
REFUSE
1.5m - 100mm Ø P.V.C. SCH. 40 PERFORATED
6 mm Ø HOLE — 150mm CENTRES
100mm Ø P.V.C. SCH. 40 CAP PERFORATED

FIGURE 4 SCHEMATIC OF GAS RECOVERY WELL

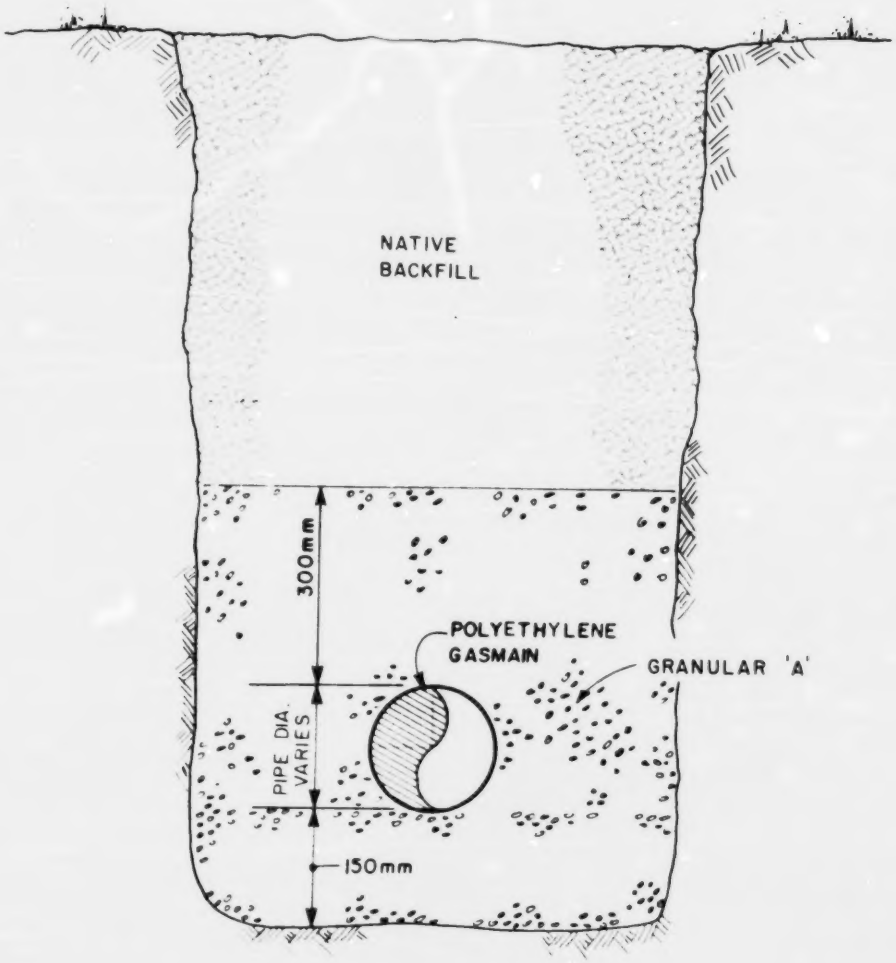
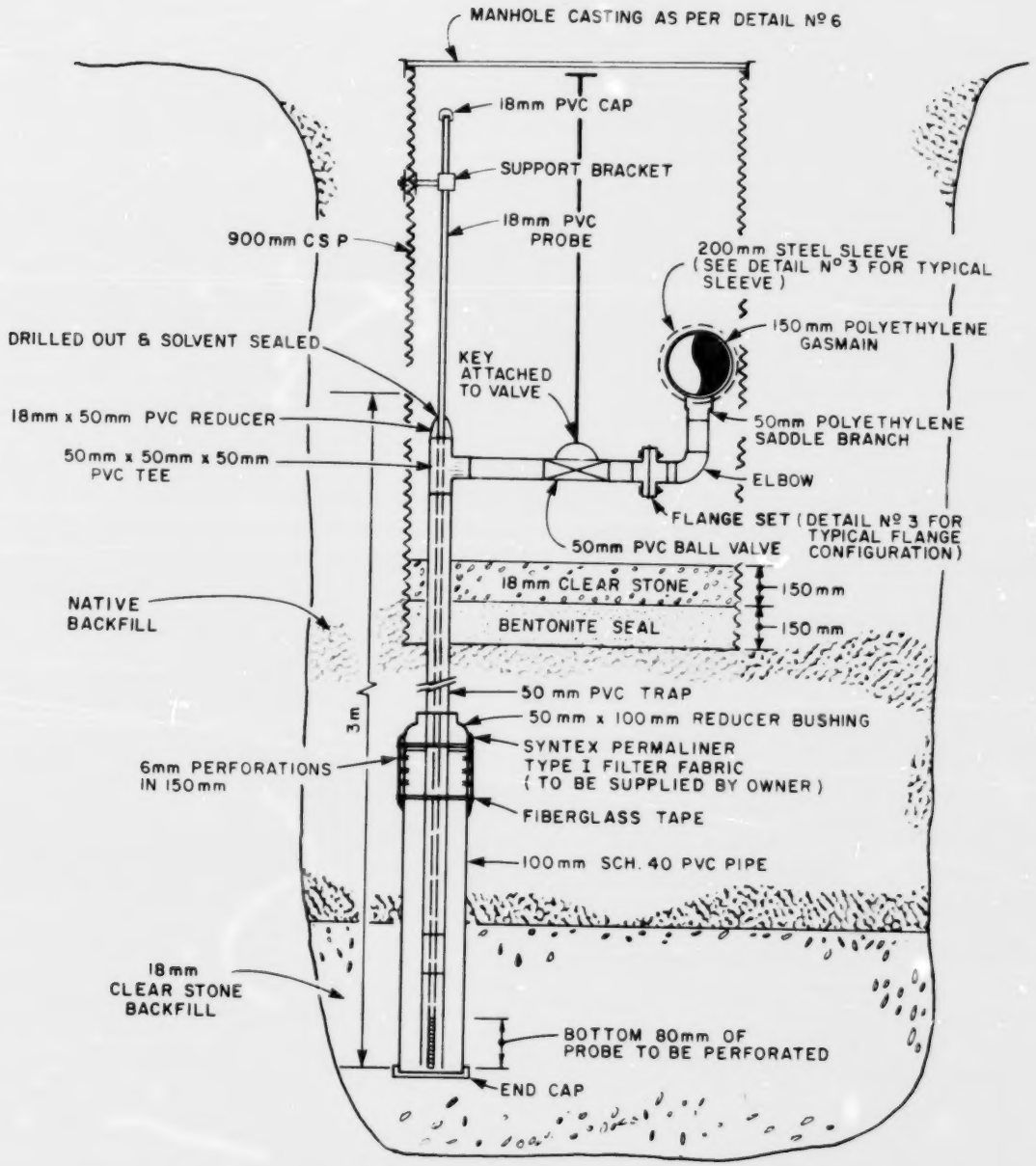


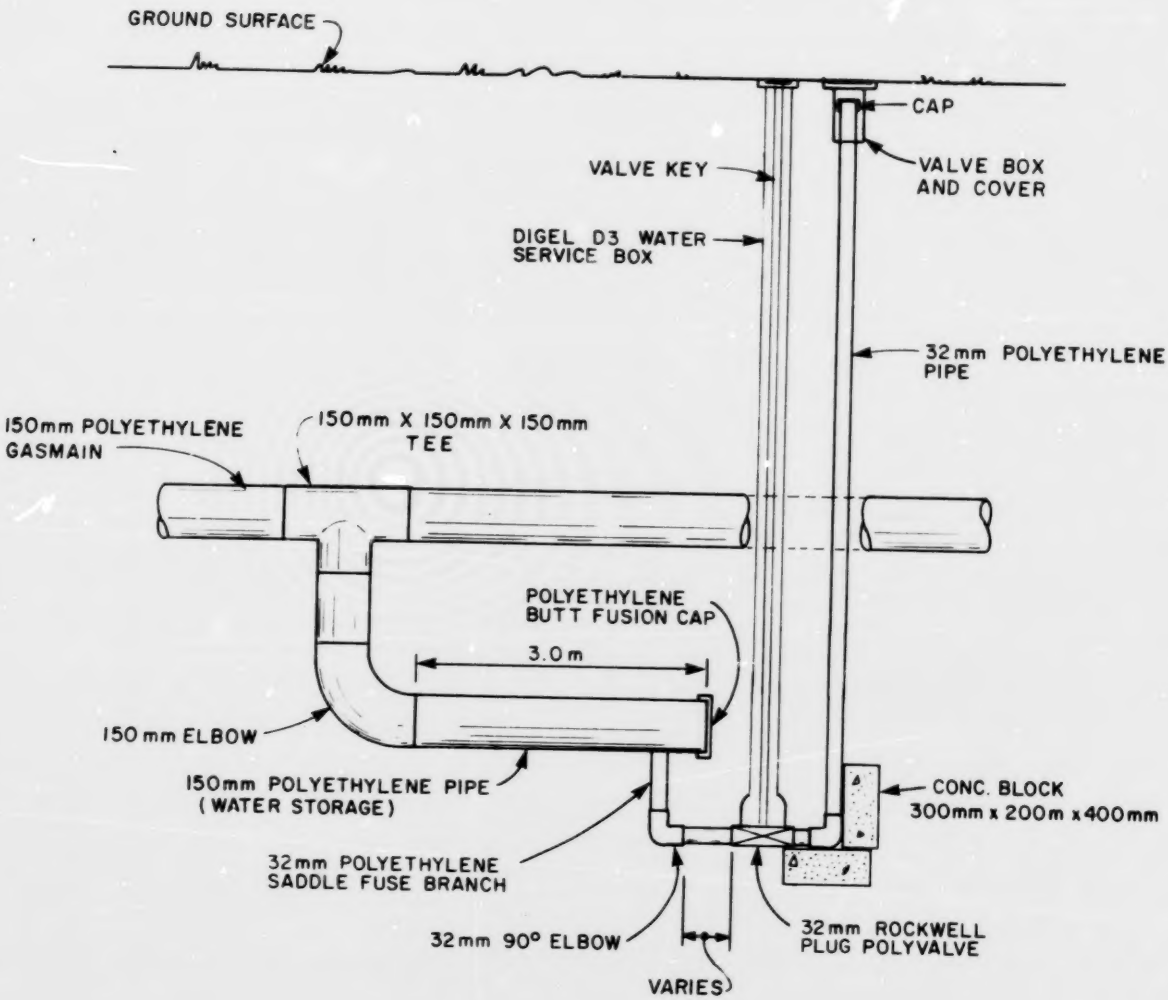
FIGURE 5 BEDDING DETAIL


MANHOLE CASTING AS PER DETAIL Nº 6
18mm PVC CAP
SUPPORT BRACKET
18mm PVC PROBE
900mm C S P
200mm STEEL SLEEVE (SEE DETAIL Nº 3 FOR TYPICAL SLEEVE)
150mm POLYETHYLENE GASMAIN
DRILLED OUT & SOLVENT SEALED
KEY ATTACHED TO VALVE
18mm x 50mm PVC REDUCER
50mm POLYETHYLENE SADDLE BRANCH
50mm x 50mm x 50mm PVC TEE
ELBOW
FLANGE SET (DETAIL Nº 3 FOR TYPICAL FLANGE CONFIGURATION)
50mm PVC BALL VALVE
18mm CLEAR STONE
150mm
NATIVE BACKFILL
BENTONITE SEAL
150 mm
50 mm PVC TRAP
3m
50 mm x 100 mm REDUCER BUSHING
SYNTEX PERMALINER TYPE I FILTER FABRIC (TO BE SUPPLIED BY OWNER)
6mm PERFORATIONS IN 150mm
FIBERGLASS TAPE
100mm SCH. 40 PVC PIPE
18mm CLEAR STONE BACKFILL
BOTTOM 80mm OF PROBE TO BE PERFORATED
END CAP

NOTE:-ALL POLYETHYLENE PIPE, VALVES AND FITTINGS TO BE (FUSED JOINTS) AS SPECIFIED

- ALL PVC JOINTS TO BE SOLVENT WELDED

FIGURE 6 MANHOLE AND WATER TRAP (Negative Pressure)



NOTE: ALL 150mm PIPE & FITTINGS TO BE DRISCOPIPE 1600 SR60 POLYETHYLENE

FIGURE 7 WATER TRAP (Positive Pressure)

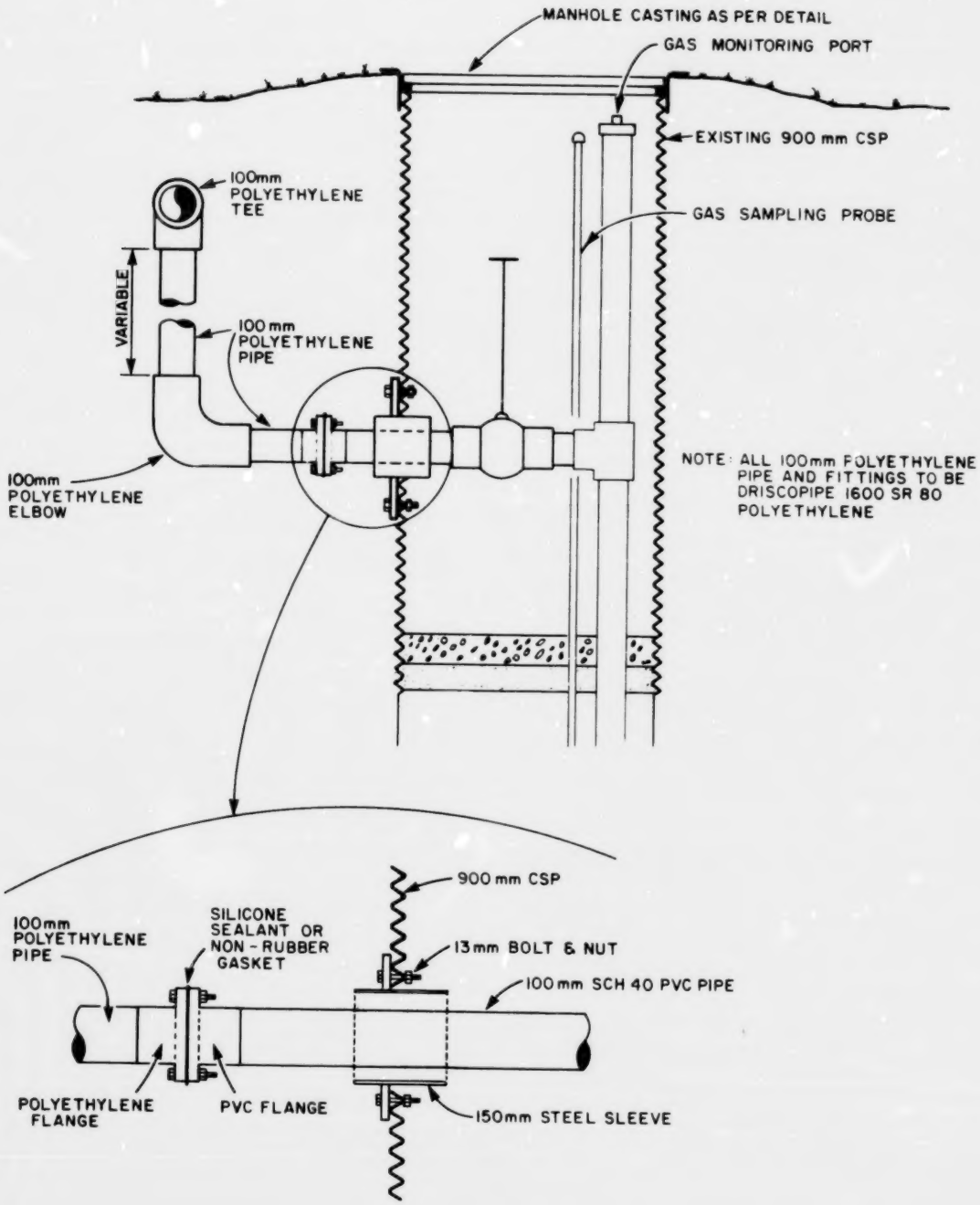

MANHOLE CASTING AS PER DETAIL
GAS MONITORING PORT
EXISTING 900 mm CSP
100mm POLYETHYLENE TEE
GAS SAMPLING PROBE
VARIABLE
100 mm POLYETHYLENE PIPE
100mm POLYETHYLENE ELBOW
NOTE: ALL 100mm POLYETHYLENE PIPE AND FITTINGS TO BE DRISCOPIPE 1600 SR 80 POLYETHYLENE
900 mm CSP
100mm POLYETHYLENE PIPE
SILICONE SEALANT OR NON-RUBBER GASKET
13mm BOLT & NUT
100 mm SCH 40 PVC PIPE
POLYETHYLENE FLANGE
PVC FLANGE
150mm STEEL SLEEVE

FIGURE 8 LATERAL CONNECTION TO EXISTING WELL

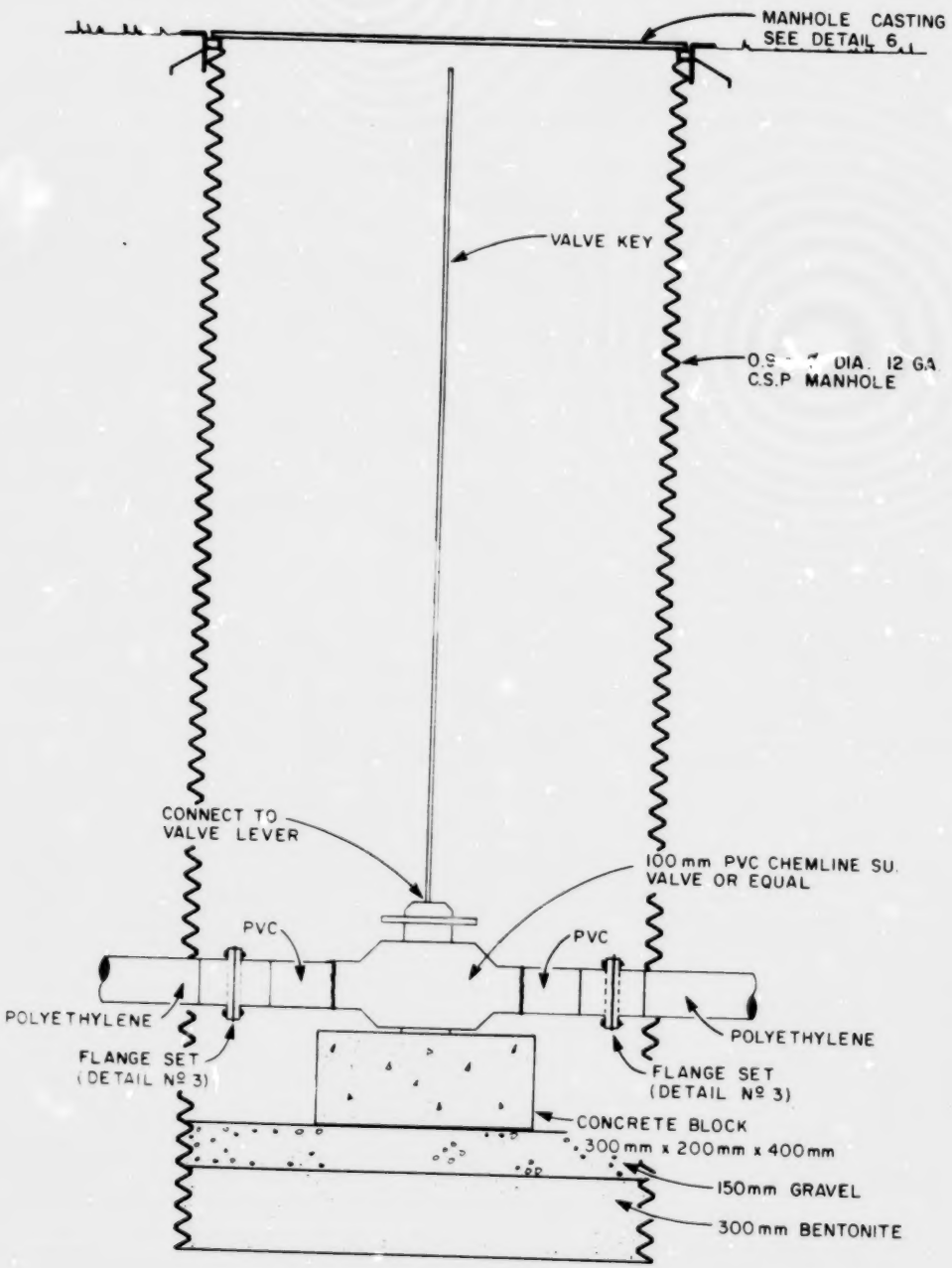
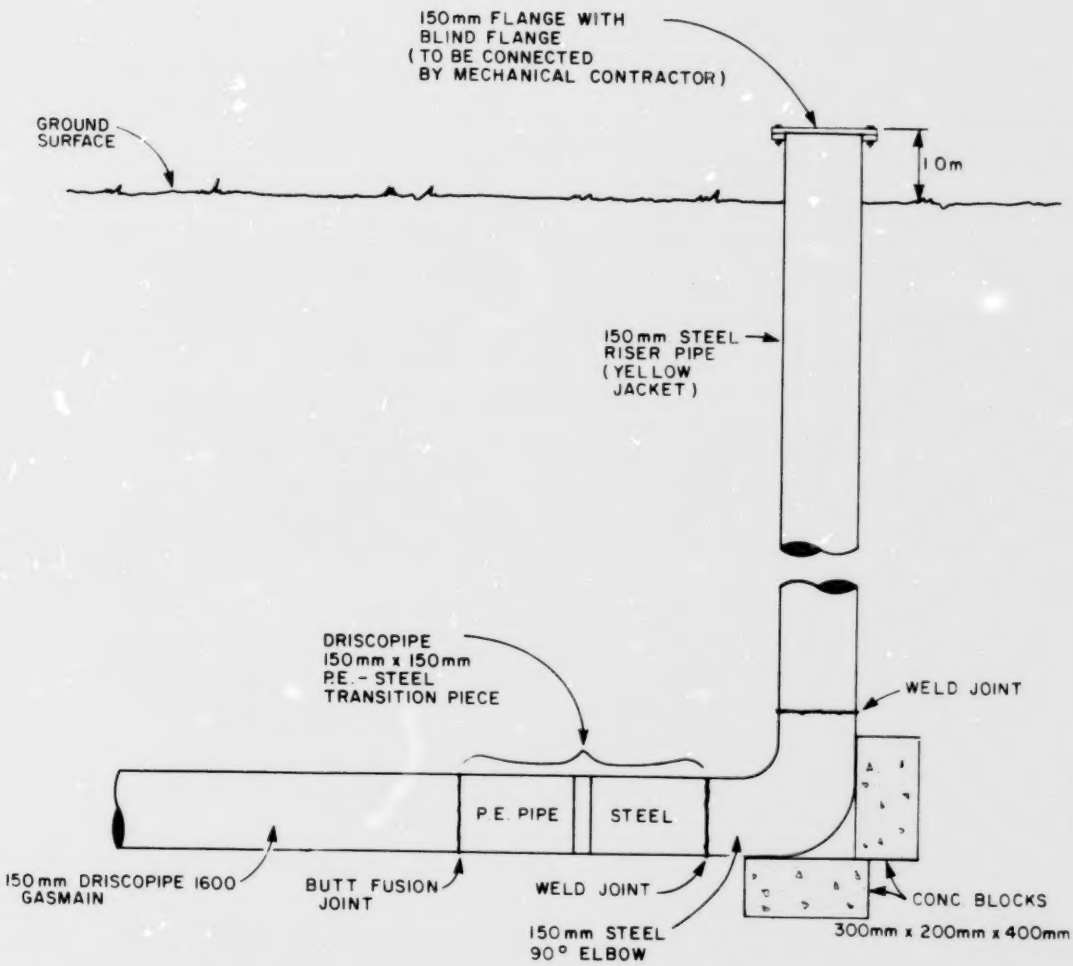
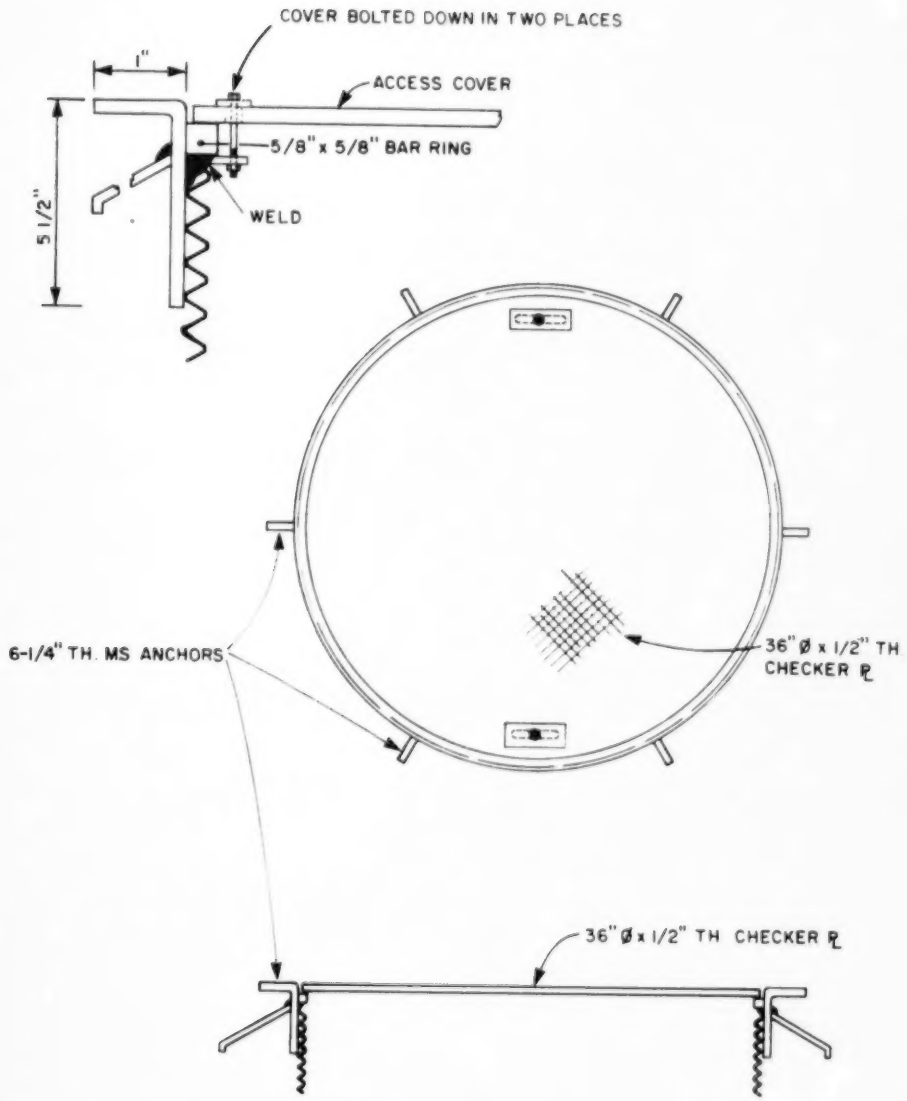


FIGURE 9 VALVE AND BOX ASSEMBLY



NOTE : PLASTIC SECTION OF TRANSITION PIPE TO BE WRAPPED IN WET CLOTH OR EQUAL HEATSINK WHEN WELDING TO STEEL TRANSITION SECTION.

FIGURE 10 STEEL SERVICE RISER



NOTE : AS MANUFACTURED BY
BEAVER MFG (1971) LTD.
HYMUS ROAD
SCARBOROUGH, ONTARIO

FIGURE 11 MANHOLE CASTING DETAIL

In general, all gas well components and drain trap constructions were made from various sizes of polyvinyl chloride (PVC) pipe. PVC pipe was used because of its relative corrosion resistance and inherent rigidity which facilitated installation.

Lateral and header gas lines were constructed of polyethylene pipe, butt-fused together. The lateral lines were constructed of 10-cm diameter SR80 polyethylene pipe. The collection header was constructed of 15-cm diameter SR80 polyethylene pipe. Polyethylene was used because it is resistant to corrosion and is more flexible than PVC pipe. Flexibility was needed to account for the possible settlement of the landfill site over time. The butt-fuse system for joining pipes was important for the prevention of gas leakage in the collection line. Typical bedding details for the pipe installations are shown in Figure 5.

The "wet" (saturated with water) nature of the landfill gas when withdrawn from the site caused condensation in the pipeline during transmission. To collect and drain this water from the site, the lateral lines in the well field were constructed to drain back to the landfill gas wells. Drain traps were installed at various intervals on the collection line to drain the water (Figures 6 and 7). All pipe had to be laid to grade because of the need for drainage. A minimum 1% grade was used when water flow for drainage was in the same direction as the flow of gas. A minimum 4% grade was required when water drainage was against the gas flow direction.

1.2.2 Gas Pumping System. The gas pumping system includes the pumphouse and all mechanical equipment required to extract the landfill gas and process it for transmission to the Bestpipe plant.

Pumphouse Construction. The pumphouse foundation was constructed as a reinforced concrete floating slab. This type of foundation was used to compensate for settling because the pumphouse was constructed on an older section of the landfill site. The pumphouse structure itself was a prefabricated steel building chosen for its relative flexibility which would also allow for possible settling at the location chosen.

A membrane and venting system were installed underneath the pumphouse foundation to prevent the possibility of landfill gas migration and buildup under the pumphouse. The membrane is a 508 µm (20 mil) polyethylene membrane with a gas transmission permeability of approximately 3.1×10^{-3} to 4.7×10^{-3} $cm^3/cm^2 \cdot d$. The venting system itself is constructed of 10-cm ABS perforated pipe surrounded by 2-cm clear stone; it vents naturally to the atmosphere by way of the vent stock and rotary ventilator.

A methane gas detector was also installed inside the pumphouse to monitor methane gas buildup in the structure and to shut down the pumping equipment if levels greater than 25% of the lower explosive limit are detected.

Mechanical System Installation. The test pumping system has been designed to recover enough landfill gas to fuel a 150 hp boiler during peak demand at the Bestpipe plant. The maximum gas recovery rate was determined to be 177 L/s of landfill gas at 30% combustible gas (methane by volume). The system was designed to operate on demand from the boiler and any excess gas not used by the boiler is automatically flared to the atmosphere.

The following major system components are listed in the order in which the landfill gas would pass through them from the well field:

1. **Centrifugal Separator** - The centrifugal separator is designed to help separate water from the landfill gas before entering the pumping equipment. The tank is designed to swirl or centrifuge the landfill gas in order to plate out water on the sides of the tank. The tank also decreases the velocity of the gas which assists the condensation process. The condensed water drains to a negative drain trap and ultimately into a sanitary sewer on the northern perimeter of the landfill site.

   The tank is made from Atlac 382 fiberglass resin with an ultraviolet inhibitor to prevent deterioration of the fiberglass from outdoor exposure. It is designed to withstand a vacuum of up to 67.7 kPa and is constructed to code requirements for vacuum vessels (i.e., CGSB 41.GP-22).

2. **Filter** - To protect the pumping equipment, a "Dollinger" model GP-105-230 low pressure filter was installed to remove any particulate matter in the landfill gas. The filter is designed to remove particles greater than 10 mm in diameter. A drain was also installed at the bottom of the filter to remove any water that condenses out in the filter tank enclosure. Also installed on the filter is a magnahelic differential pressure gauge. This gauge measures the amount of head loss or pressure drop through the filter. By monitoring the head loss through the filter one can determine when the filter medium needs to be cleaned or replaced.

3. **Oxygen Monitor** - A "Beckman" model 7003 oxygen monitor was installed in line before the pump to measure the amount of oxygen in the landfill gas stream. The amount of oxygen in the landfill gas stream is monitored to determine if there are any system leaks or if outside air is being drawn in through the cover soils. Landfill gas is produced under anaerobic conditions and should have no oxygen content.

4. **Vacuum and Pressure Switches** - "ASCO (Tripoint)" explosion-proof fixed differential pressure switches were installed on discharge and intake sides of the pumping system. These switches constantly monitor system vacuum and system discharge pressure. If too much vacuum or overpressure is produced, the system is automatically shut off through the pressure switches. The vacuum switch is currently set on 33.9 kPa vacuum while the discharge pressure switch is currently set at 103.4 kPa.

5. **Landfill Gas Pump** - A "ROOTS" Model 409RCS-J Wispair Rotary Lobe Blower was used as the landfill gas recovery pump. An explosion-proof 40 hp Brown Boveri Canron (BBC), U.S. frame motor was used to drive the blower. This blower has a total possible pressure differential between inlet and discharge of 103.4 kPa. During Phase I, the system operated at a pumping rate of 177 L/s with a 20.3 kPa vacuum and a 48.3 kPa discharge pressure.

   A 12.7 cm backcheck valve is installed on the pump discharge to prevent possible damage from opposite spinning of the pump impellors during the on and off operation (boiler demand for fuel) of the landfill gas system.

6. **Intake and Discharge Silencers** - Universal Model RDY-5 Silencers were placed on the intake and discharge of the pump. These silencers were installed to reduce the noise impact from the intake and discharge of the pump.

7. **Aftercooler** - A "Pneumatech Turboflow Aftercooler" Model PAC77 was installed after the landfill gas pump. The aftercooler chills the landfill gas after pump compression using ambient outside air. It was sized to provide 70% moisture removal or water removal from the landfill gas. The aftercooler is run by a 3/4 hp electric motor.

   Since the aftercooler was installed outside the pumphouse to take advantage of ambient air temperature no explosion-proof mountings or motors were required.

   The water collected from the aftercooler was drained through an automatic drain trap into the sanitary sewer. The drain lines leading from the aftercooler were heat traced above ground level to prevent freezeup in winter.

8. **Odourizer** - A "Peerless Manufacturing Company" Model 470 bypass type odourizer was used to odourize the landfill gas before transmission to Bestpipe. The landfill gas was odourized to readily determine landfill gas transmission system leaks or landfill gas leaks at the Bestpipe plant.

9. **Flare Assembly** - An excess landfill gas flare system was incorporated into the mechanical system. The landfill gas pumping system was sized to meet maximum boiler fuel rate demands. Since the boiler fuel rate demand varies in accordance with the steam demand in the plant, the excess landfill gas is flared to the atmosphere.

   The flare and flare equipment such as the flame arrestor and pressure regulator are manufactured by "Varec".

   A separate propane pilot assembly has been added to the flare. This system is designed to ignite the excess flare gas with a propane pilot at timed intervals when the pumping system is running. This ensures that the landfill gas will be ignited and flared.

10. **Valves** - Various valves have been incorporated in the pumping system. These are 10-and 15-cm non-modified, standard, gas plug type valves manufactured by "DeZurik".

1.2.3 Transmission and Utilization System. The transmission system includes: the transmission line, metering equipment, and boiler connections at the Bestpipe plant. The

transmission line incorporated the same 15-cm polyethylene butt-fused pipe previously described.

Positive pressure blowouts were installed at low points in the transmission line. These blowouts use landfill gas pressure to blow water out of the storage containers installed beneath the transmission line (Figure 7).

The metering station at Bestpipe has a 15-cm Rockwell turbine gas meter. Readout on the gas meter is for cumulative gas usage and no automatic pressure or temperature compensation devices were installed. A sampling port was provided on the meter. The landfill gas is periodically sampled at this point with a handheld combustible gas meter for measuring methane concentrations in the landfill gas.

Conversion of the boiler at the Bestpipe plant to run on landfill gas involved the installation of a second gas train onto the boiler. The burner housing was also adapted for landfill gas. Orifices in the burner housing were increased in size to allow passage of the greater flow of landfill gas.

These boiler conversions were designed by Cleaver-Brooks Inc. for their 150 hp boiler at the plant.

1.3 Gas Recovery and Utilization System Safety Features

Many safety features were built into the landfill gas recovery and utilization system to ensure the safe operating of the system at all times.

1.3.1 Gas Recovery System Safety Features. Separate valves were installed on all individual components of the gas extraction system including all wells and negative drain traps. The valves allow for adjustment of the wells and the shutdown of any malfunctioning well or negative drain trap.

Valves were placed at lateral lines 1, 2 and at the pumphouse. These valves enable well lines 1 and 2 to be completely shut off through the turn of one valve or for the whole system to be isolated from the pumphouse system by turning off the valve at the pumphouse.

1.3.2 Landfill Gas Pumping System Safety Features. Many safety features were incorporated in the landfill gas recovery system:

1. **Valves** - Valves were placed into the pumping system so that individual components and the entire system could be easily isolated from the transmission or the extraction system. Valves which isolate the total pumphouse system from the extraction or transmission system can be reached from the outside with no need to enter the pumphouse itself.

2. **Pumphouse Safety** - The pumphouse space was classified as a Class 1, Group D, Division 2 location by the Ontario Ministry of Labour. All electrical fixtures within the pumphouse, therefore, had to be explosion-proof rated. The only electrical equipment located inside the pumphouse were the lights and the pump electric motor (both explosion-proof). All other electrical equipment was mounted in weatherproof boxes on the outside wall of the pumphouse.

   An exhaust fan of capacity for thirty air changes per hour was also installed in the pumphouse. This fan operates whenever the pump is in operation, and prevents the buildup of methane gas to explosive levels, due to methane migration, or possible landfill gas leakage through the pump bearings.

   The methane venting system was also installed beneath the landfill pumphouse and a methane gas monitor was installed inside the pumphouse. If methane concentrations within the pumphouse exceed 25% of the lower explosive limit (LEL), the monitor automatically shuts down the pump operation and turns on the exhaust fan. An alarm is sent to a nearby 24-hour manned station to indicate a failure of the pumphouse system.

3. **Mechanical System** - The mechanical system safety features consist mainly of the oxygen monitor and the high and low pressure switches.

   The oxygen monitor is designed to shut off the pumphouse system if oxygen concentrations in the gas line become higher than approximately 6% (oxygen by volume). The vacuum switch and the pressure switch shut off the system if any of the pressure settings on the switches are surpassed.

1.3.3 Flare System Safety. A flame arrester was installed on the flare line to prevent any possible backflame from the flare down into the gas transmission system.

1.3.4 Transmission System Safety Features. Systems are in place for the odourization of the landfill gas to allow easy detection of any leaks in the landfill gas transmission system. The landfill gas has a distinctive odour; therefore, it has not been necessary to utilize this system.

At the Bestpipe plant itself, a control panel equipped with alarms and buzzers indicates if the pumphouse has been shut down for any malfunction.

The Bestpipe boilers are designed to run on either landfill gas or natural gas and the system is designed such that both fuels cannot run together. Flame arresters are also installed in the landfill gas train to avoid explosions in the landfill gas line. The landfill gas train was designed to meet gas code specifications for safety including a manual shut off valve and dual automatic low pressure and high pressure shut off valves.

2 PHASE I - PROJECT CONSTRUCTION

Table 1 lists the timetable for the various stages of the Phase I construction from tender letting to the Phase I system being placed in an operational mode.

In general, no unusual construction techniques were implemented during construction of the project. The following sections give brief descriptions of the techniques used for the major construction stages.

2.1 Landfill Gas Well Construction

Phase I landfill gas wells were installed using the materials shown in Figure 4. The 91-cm diameter boreholes were augered into the refuse using a 91-cm auger truck-mounted drill rig. As can be seen from Table 1, the fifteen installed gas wells for Phase I took approximately two weeks to complete. Installation of the gas wells went smoothly and no major problems were encountered.

2.2 Landfill Gas Recovery System and Transmission System Installation

All pipeline construction for the landfill gas extraction system and transmission system was carried out using standard pipe laying practices. Bedding details for all pipe areas are shown in Figure 5 and all or most excavation was carried out using either a track or rubber tire-mounted backhoe. All excavation for the negative drain traps was pre-drilled using the 91-cm auger truck-mounted drill rig used during the gas well systems installation.

Landfill gas line installation ranged at a rate of on the order of 46 to 91 m/d in refuse material. This rate was controlled by the amount of time it took to connect well installations and to install negative drain traps.

After installation of the landfill gas line, the line was subjected to a pressure test. The landfill gas line was tested with compressed air at 103.4 kPa and was required to hold this pressure for a minimum 12-hour duration or overnight.

In order to ensure safety on the site, a few basic safety precautions were taken while working on the landfill site:

1. an air blower of sufficient capacity was required to be on site to vent fumes from landfill gas from the working area when needed;
2. a Scott Air Pak (or equivalent) and a person knowledgeable on its use were required on site;
3. no smoking was permitted in the open excavation area; and

TABLE 1 PHASE I - CHRONOLOGY OF MAJOR CONSTRUCTION EVENTS

Event		Date
1.	Landfill Gas Well Installation	March 22, 1982
2.	Bestpipe Boiler Conversion	March 31, 1982
3.	Landfill Gas Well Installation Ends	April 1, 1982
4.	Construction of Transmission Line on Bestpipe Property Begins	April 12, 1982
5.	Construction of Transmission Line on Bestpipe Property Ends	April 28, 1982
6.	Call For Tender - Contract 82-17* - Contract 82-18*	May 15, 1982
7.	Tender Open - Contract 82-17 - Contract 82-18	May 27, 1982
8.	Tender Award - Contract 82-17	June 24, 1982
9.	Construction Begins - Contract 82-17	July 13, 1982
10.	Tender Award - Contract 82-18	July 21, 1982
11.	Equipment Ordering - Contract 82-18	July 22, 1982
12.	Pumphouse Construction Begins	July 26, 1982
13.	Substantial Completion of Contract 82-17	August 20, 1982
14.	Substantial Completion of Pumphouse Construction	August 27, 1982
15.	Mechanical Equipment Installation Begins	August 30, 1982
16.	Contract 82-18 Placed on Maintenance	September 15, 1982
17.	Mechanical Equipment Installation Ends	October 22, 1982
18.	Mechanical System "Debugging" Begins	October 22, 1982
19.	Mechanical and Extraction System "Debugging" Complete	November 26, 1982
20.	System Placed in Operational Mode	November 29, 1982
21.	Intermittent Operation of System	November 29, 1982- July 26, 1983
22.	30-day Pumping Test	July 26, 1983 - August 26, 1984

* Contract 82-17 - Regional Municipality of Waterloo Contract
Landfill Gas Line Construction
Kitchener Landfill Site, Kitchener
- awarded to OPSCO Ltd., Cobalt, Ontario

* Contract 82-18 - Regional Municipality of Waterloo Contract
Pumphouse Construction
Kitchener Landfill Site, Kitchener
- awarded to Groff Plumbing and Heating Limited, Waterloo, Ontario

4. no open flame or other source of ignition was allowed in the trench areas.

Construction of the landfill gas extraction system and transmission system went smoothly and almost on schedule. Only one major difficulty was encountered during construction. A considerable odour occurred from uncovered refuse and residents in the immediate area complained. It was decided that exposed refuse was to be covered immediately with any available soil on site. The contractor conducted this; however, it was necessary to use previously stripped topsoil from the area for this purpose. Covering the refuse helped to alleviate some odour problems, but the odour persisted until construction had been completed.

It should also be noted that the use of topsoil for covering the refuse caused considerable mixing of soil and refuse. Some refuse was still noticeable along the surface after gas line construction was completed necessitating additional cleanup after construction. During Phase II, Part A, this problem was controlled by setting out distances in the specifications that the contractor was not permitted to excavate in refuse before pipe installation. Also the contractor was not permitted to leave any uncompleted or open trench areas or any on-site refuse piles at the end of the working day.

2.3 Mechanical System Installation

All equipment was installed as per manufacturer specifications; however, some problems were encountered with the equipment delivery. In particular, the flare and related flaring equipment were shipped from California and considerable delays were experienced due to trucking strikes and Customs approvals. Mechanical equipment installation for Phase I, therefore, was not completed until late October 1982 (Table 1).

2.3.1 System Start-up Debugging. Initially, the pumping system was tested with outside air to determine if there were any problems. These problems included minor difficulties with regulator and pressure relief settings on the excess gas flare system and the need for an additional check valve at the pump discharge. These problems were easily rectified.

The system was then run on landfill gas. It was found that the pressures required for recovering the landfill gas and transporting it to Bestpipe were considerably lower than anticipated. Therefore with lower pressures, and initially designed pump sheave, it was calculated that a pumping rate of approximately 283.2 L/s was attained while the design rate was only 177 L/s. The sheave was subsequently changed, and the design pumping rate of 177 L/s was attained.

As stated previously, it was anticipated that the reduced pressures would mean that the existing pump would have a capacity of approximately 377.6 L/s which would be sufficient for both Phase I and Phase II systems combined.

The original flare system included an electronic ignition and flame sensing rod which would fire the landfill gas in the flare when excess landfill gas was produced. This system was not reliable for excess landfill gas flare ignition, partly because of varying landfill gas composition, and the difficulty in adjusting the system. The separate propane system, therefore, was installed on the flare system.

The boiler was also tested on landfill gas and all boiler systems were found to run satisfactorily requiring only minor adjustments.

3 PHASE I - LANDFILL GAS SYSTEM OPERATION

3.1 Phase I - Operational Difficulties

In general, the mechanical systems of the project have operated well. All major Phase I operational difficulties occurred in the landfill gas extraction system portion of the project. The major Phase I difficulties centered around water and low methane concentrations in the landfill gas collected.

1. **Condensate Water Freezing** - After the system was in full operation, it was found that during very cold periods the condensate water in the aftercooler froze causing the system to shut off. The fan on the aftercooler was, therefore, turned off during very cold periods to allow some of the condensate water to pass beyond the aftercooler. Subsequently, the water froze in the above ground gas lines, necessitating the insulation of the above ground lines with urethane foam to alleviate the problem. To date, no further problems with freezing in the gas lines have occurred.

2. **Water in Gas Wells and Lines** - During the mild winter in this area, the entire landfill site area became very wet. This water had a two-fold effect on the system. Water infiltrated the landfill site through the recent excavations and collected in some gas production wells. During the landfill gas system operation, up to seven out of the fifteen wells were out of commission due to water sealing off the well screen.

   It is also believed that infiltrating water had saturated the negative drain trap sumps. This prevented condensed water in the landfill gas collection line from draining properly. Water in the collection line did not cause a system stoppage but did cause the vacuum pressure on the site to surge between 13.5 to 20.3 kPa. To date this condition has cleared as normal conditions have returned to the site.

3. **Combustible Gas Concentration** - Initial methane concentrations during Phase I in the landfill gas at start-up varied between 35% to 45%. The methane concentrations then dropped to between 20% and 30% during Phase I. The boiler is not capable of producing enough steam pressure at high fire with the methane concentration lower than 30% to 35%.

   The decrease in combustible gas concentration during Phase I was believed to be due to the landfill site becoming aerobic. This had been created by the drawing in of outside air through the cover from the overpumping of wells that had not been shut down due to water problems or low landfill gas concentrations. Where excavations were made for construction, large amounts of outside air entered the site creating aerobic conditions.

3.2 Phase I - Gas System Evaluation

The Region of Waterloo undertook an evaluation of the Phase I well field and identified a considerable variance in methane concentrations at each well. The well field was then balanced for gas concentration rather than pressure. This reduced the gas concentrations by increasing air intrusion into the landfill.

During the spring of 1983, CRA undertook an investigative program to determine the cause of the low methane production rate monitored during Phase I. This program included monitoring pressure concentrations, gas concentrations, and temperature at each well on several occasions. The results of this evaluation indicated that:

1. select portions of the landfill cover were allowing air infiltration into the landfill, and hence into the landfill gas, causing the landfill to become aerobic and decreasing methane production;

2. the gas production rate on the southern sector of the landfill was not as high as originally estimated;

3. additional gas wells would be required to reduce suction pressure across the site, as well as reduce the gas concentration rate per well; and

4. a pumping test on the northern sector of the landfill site indicated good quantity and quality of landfill gas.

As a result of the investigation conducted by CRA, the following recommendations were presented to the Region for optimization of the Phase I system:

1. conduct a long-term pumping testing of the northern sector landfill to determine if the northern sector is suitable for landfill gas recovery;

2. subject to confirmation by the gas pumping test the installation of an additional four gas wells in the southern sector of the site and three in the northern sector;

3. seal off all existing gas wells from air intrusion;

4. place a PVC liner over the trench area in the vicinities of wells where air infiltration is noted; and

5. repair two of the existing wells to drain properly.

Implementation of these recommendations was carried out in the fall of 1983 as part of the Phase I - Optimization study.

4 PHASE I - OPTIMIZATION

4.1 Field Work

In the late fall of 1983 the Phase I optimization recommendations were implemented at the Kitchener landfill site. A 30-day pumping test was conducted on a 12.2-m deep, 5.1-cm diameter well installed on the northern section of the landfill. The location of the gas well is seen in Figure 12 and the gas well installation detail is presented in Figure 13. The test commenced at noon on July 26, 1983, and was shut off at approximately noon on August 26, 1983. The pump operated at a rate of approximately 47.2 L/s. The daily monitoring results of the pumping test are presented in Figure 14.

The results of the pumping test indicated that good quality landfill gas was available in the northern portion of the site. However, due to the age of the site it was difficult to predict how long this gas would be produced. Based on the results of the pumping test, it was recommended that the proposed optimization program be implemented. The major Phase I optimization construction events are summarized in Table 2 in chronological order.

TABLE 2 PHASE I - OPTIMIZATION CHRONOLOGY OF MAJOR CONSTRUCTION EVENTS

Event	Date
1. Installation of concrete seals in the bottom of all south wells.	September 20, 1983 - December 1, 1983
2. Installation of four new landfill gas wells and connection to existing laterals in south field.	September 20, 1983 - December 1, 1983
3. Installation of three new landfill gas wells in the north field and connection with collector header.	September 20, 1983 - December 1, 1983
4. Installation of orifice and gas probes.	September 20, 1983 - December 1, 1983
5. Repairs to wells No. 11 and No. 14.	September 20, 1983 - December 1, 1983
6. Optimized system put in full operation.	January 10, 1984

FIGURE 12 GAS WELL LOCATION

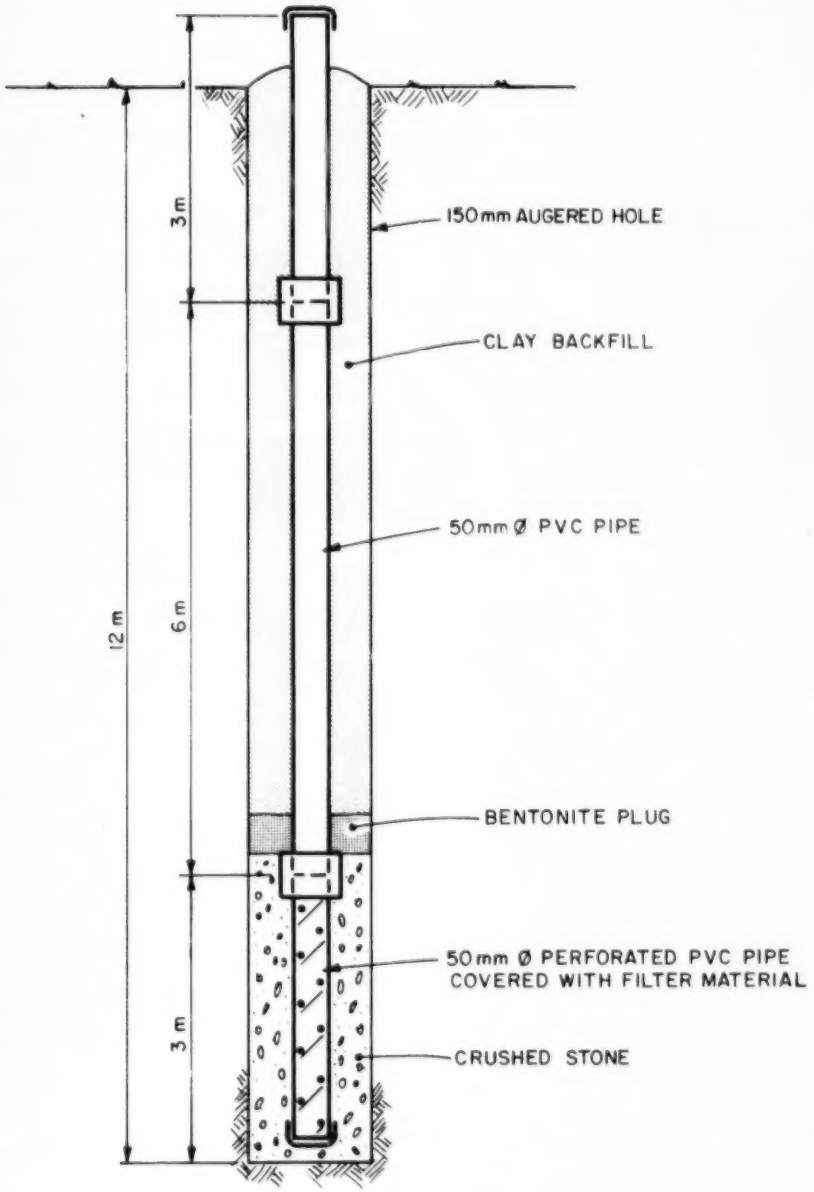


FIGURE 13 WELL INSTALLATION AT GW1-83

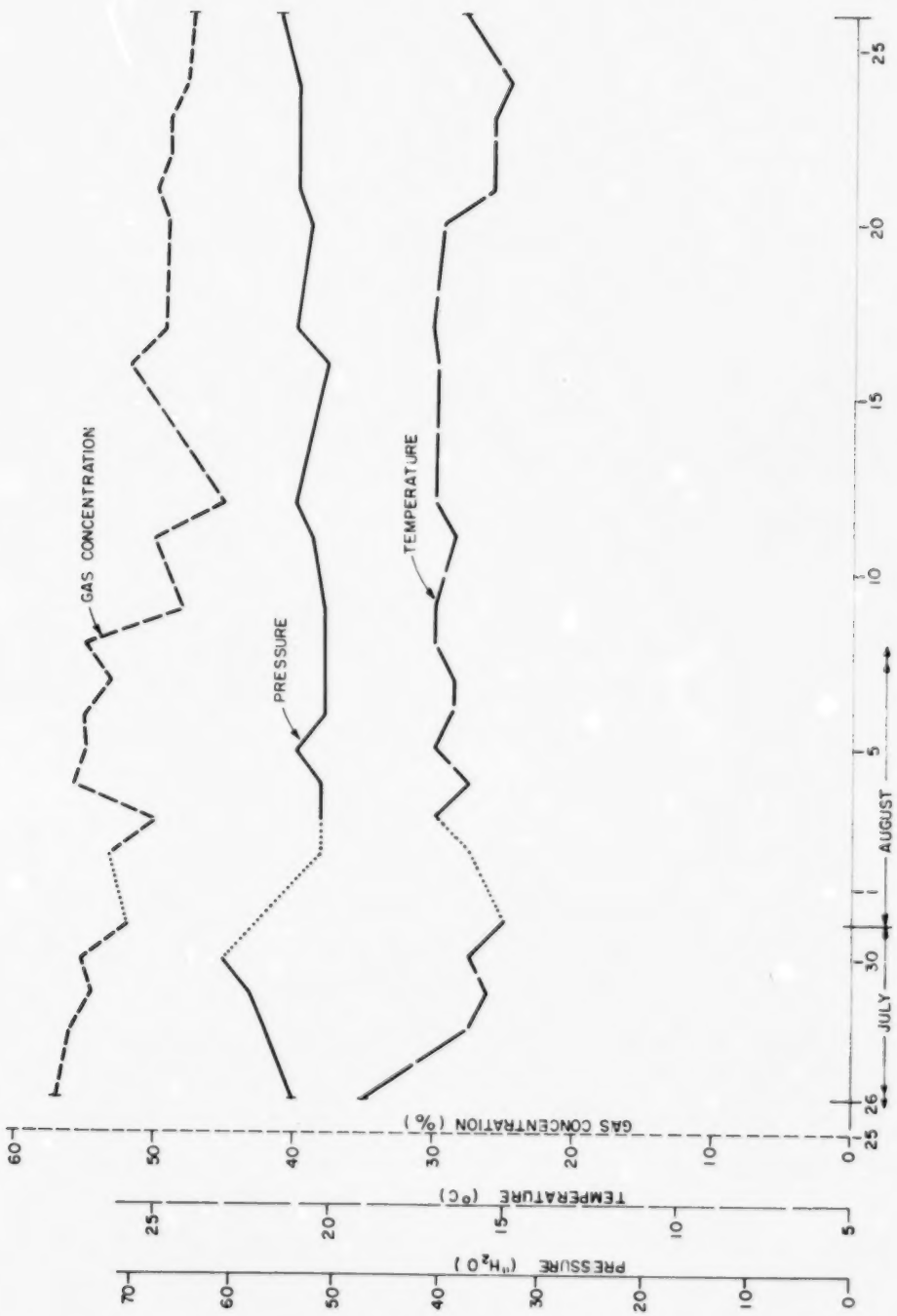


FIGURE 14 PHASE I - OPTIMIZATION: PUMPING TEST MONITORING DATA

Figure 15 shows the complete Phase I system following the optimization program. In Phase I-Optimization, the construction of the gas wells was changed to prevent air intrusion and to make the wells more accessible for monitoring. Typical well installation is shown in Figure 16.

In early January 1984, the optimized system was in full operation; however, field monitoring and system improvements were on-going. During the first half of 1984 the following field work was conducted:

- the installation of five gas probes in the northern portion of landfill;
- the draining of three water traps along the gas distribution line;
- daily monitoring of the combustible gas concentration at the pumphouse and north and south orifices;
- weekly monitoring of the pressure and methane concentrations in the north and south well fields;
- the capping of sections of the south field with a PVC liner and seeded topsoil; and
- the Regional Municipality of Waterloo arranged for repairs to the aftercooler drain trap and the positive pressure drain trap No. 1.

4.2 System Operation

The system was put into full operation on January 10, 1984, and ran continuously until February 2, 1984, when the system was shut down because of a pump mechanical problem. The pump malfunction was a result of iron oxide buildup on the pump impellors.

During this 23-day period, the system extracted landfill gas at a flow rate of 118 L/s and maintained a methane concentration between 40% and 50%.

On March 30, 1984, the gas system was put back into operation and the Bestpipe boiler was put on line using landfill gas. The system ran problem free from March through the summer of 1984. Typically, the boiler was operated on landfill gas for 10 to 12 hours daily to produce steam for the kiln curing.

The north well field provided approximately 66 to 83 L/s of the total 118 L/s and maintained a methane concentration between 40% and 50%. The average gas concentration at the south orifice was 37%; however, fluctuations between 14% an 48% were monitored.

Although moderated, the fluctuations in the south gas well field were reflected in the pumphouse readings. The very low methane readings in the south well field were attributed to missing well caps as a result of vandalism.

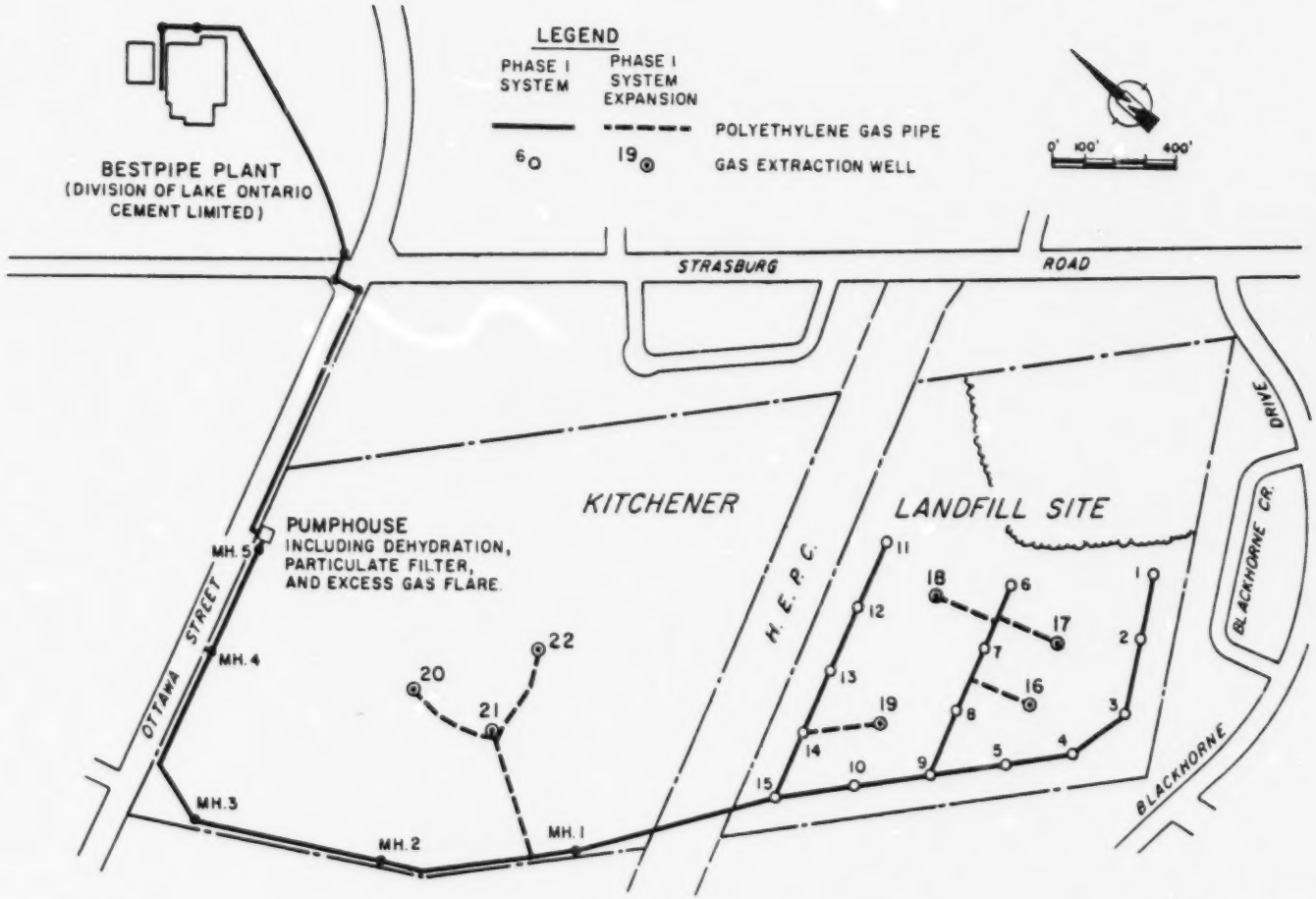


FIGURE 15 PHASE I - LANDFILL GAS RECOVERY SYSTEM EXPANSION

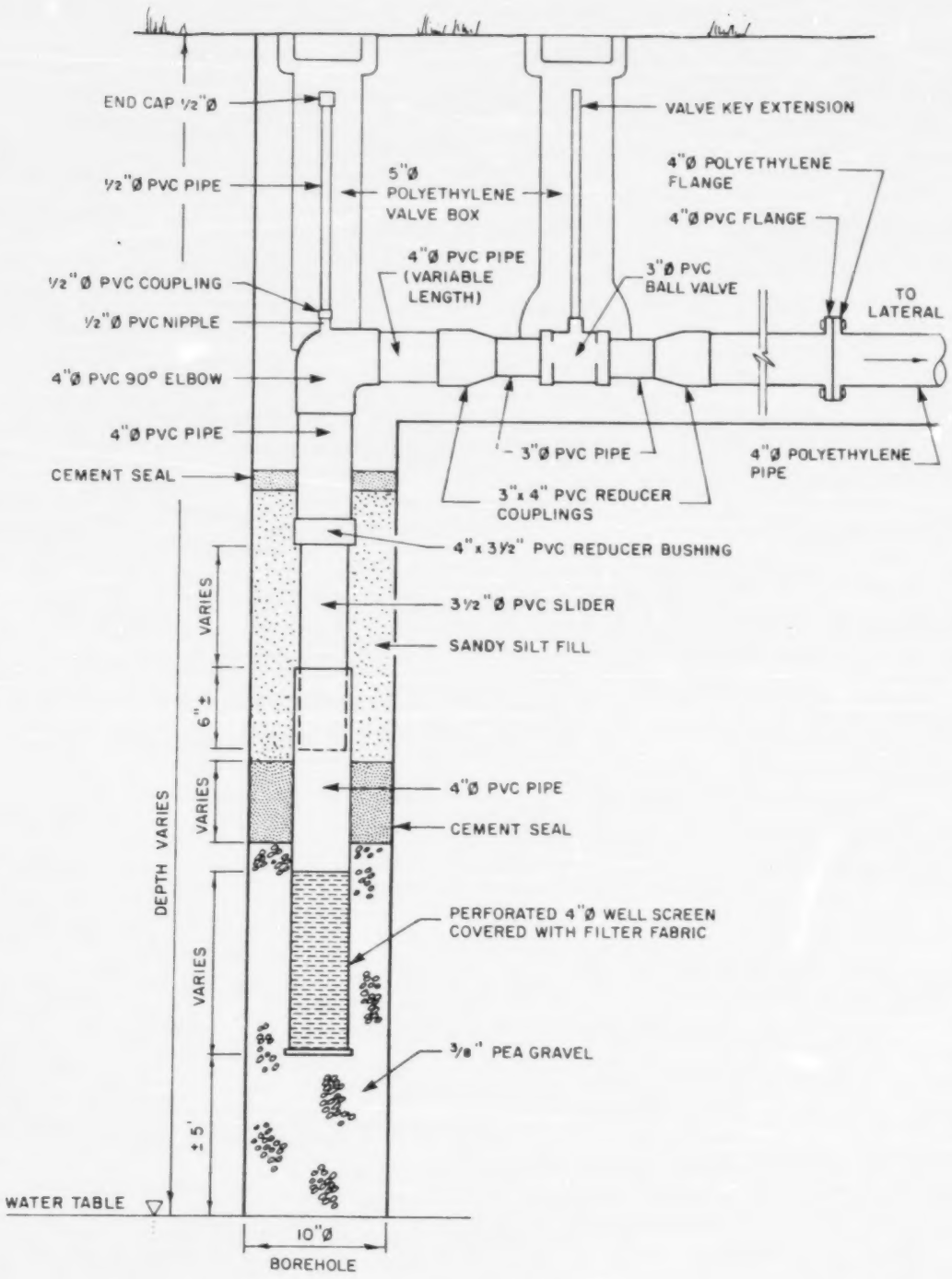


FIGURE 16 TYPICAL PHASE I - OPTIMIZATION AND PHASE II - EXTRACTION WELL INSTALLATION

Oxygen concentrations in the spring of 1984 ranged between 0.6% and 4.8%. Concentrations greater than 2.4% were again a result of vandalized well caps. When all wells and probes were properly capped, the oxygen levels in the landfill gas remained between 1.8% and 2.4%.

5 PHASE II

After the continuous problem-free operation of the system during the summer of 1984, it was proposed that Phase II of the project, as outlined in the original DRECT proposal, be split into two parts: Phase II, Part A and Phase II, Part B. This staging was proposed in light of the experience gained during Phase I, and the Phase I - Optimization work previously conducted. A cost breakdown of Phase II is given in Table 3.

Phase II, Part A includes the installation of additional wells in the northern landfill section, and the testing of these wells to ensure sufficient gas quantity and quality to fuel a second boiler at the Bestpipe plant.

Depending on the success of Phase II, Part A, Phase II, Part B was to include the installation of additional pumping and dehydration equipment and boiler conversions, to fuel the second boiler at Bestpipe.

In order to amend the original DRECT contract to include this two-part section for Phase II, a formal proposal was prepared and sent to Environment Canada. This proposal included:

1) an outline of the proposed Phase II changes entitled "Proposal for DRECT Funding, Phase II, Parts A & B, Gas Recovery System, Kitchener Landfill Gas Utilization Project", prepared by CRA on behalf of the Region for Environment Canada.

   This document dated September 13, 1984, explains the two-part approach to Phase II, and provides backup documentation regarding the entire project.

2) documentation from both the Region and Bestpipe including a statement that they would continue with the project given the successful completion of Phase II, Part A (as outlined in the September 13, 1984 DRECT proposal).

   This documentation of support by the Region and Bestpipe is included in the September 13th proposal in the form of a Council Resolution by the Region dated July 13, 1984.

5.1 Phase II - Construction Work

Between October 9, 1984, and November 8, 1984, the construction portion of Phase II, Part A on the Kitchener landfill gas utilization system was completed as outlined in the September 13, 1984, proposal, and summarized on Table 4. The work conducted included:

- the design and installation of nine new gas pumping wells on the northern landfill area;
- connection and supervision of these nine new wells, and a previously installed pump test well (a total of 10 wells) into the existing pumping system;

TABLE 3 PHASE II - KITCHENER LANDFILL SITE COST BREAKDOWN

Item		Cost
PART A - EXPANSION OF GAS WELL FIELD		
1. Well Construction:		
1.1 Materials -		
9 wells @ $700 for PVC material each		$ 6 300.00
9 wells @ $100 stone and concrete each		900.00
1.2 Drilling, Installation and Supervision -		
72 hours drilling @ $125/h		9 000.00
72 hours supervision @ $40/h		2 880.00
9 days auger rental @ $150/d		1 350.00
	TOTAL	$ 20 430.00
2. Line Construction:		
2.1 Materials -		
2400 ft or SR80 4"ϕ Poly pipe @ $2.75/ft		$ 6 600.00
12-4"ϕ Poly flanges @ $55/flange		660.00
10-4"ϕ Poly tees @ $38.50/tee		385.00
12% tax on above		917.00
2.2 Trenching, Installation and Supervision -		
92 hours trenching @ $57.50/h		$ 5 290.00
184 hours labour @ $23/h		4 232.00
92 hours supervision @ $40/h		3 680.00
18 hours backhoe @ $52/h		936.00
10 hours truck @ $40/h		400.00
Fusion four days @ $575/d		2 300.00
Topsoil 300 yd^3 @ $8/d		2 400.00
Seed nine bags @ $70/bag		630.00
Oriface Place Replacement		1 000.00
	TOTAL	$ 29 430.00
3. Engineering:		
Engineering Design, Approvals, Administration, Representation, Testing and Performance Evaluation		$ 10 000.00
Total Phase II - Part A Cost Estimate:		
1. Well Construction		$ 20 430.00
2. Line and Trenching Construction		29 430.00
3. Engineering		10 000.00
TOTAL UPSET COST, PART A		$ 59 860.00
PART B - EXPANSION OF GAS PUMPING SYSTEM		
4. Supply and Install:		
- two regrigerant aftercoolers at 300 cfm/cooler at 15 psi		
- 1-300 cfm blower at 15 psi differential		
- related mechanical and electric equipment		$ 81 556.00
5. Engineering Design, Supervision, Commissioning and Reporting		15 000.00
6. DRECT Funding Engineering Report		9 000.00
Total Budget Cost, Part B		$105 556.00
TOTAL ESTIMATED PHASE II COST		$165 556.00

The total cost for Phase II - A and B is estimated at $165 556. The estimated cost for Phase II - Part A is $60 000, and $105 556 for Phase II - Part B.

TABLE 4 PHASE II, PART A - CHRONOLOGY OF MAJOR CONSTRUCTION EVENTS

Event		Date
1.	Installation of nine new gas pumping wells on the northern landfill area	October 9, 1984 - November 8, 1984
2.	Connection of these nine wells and one previously installed well into system	October 9, 1984 - November 8, 1984
3.	Changeover of the pumping system to provide a flow rate of approximately 248 L/s	October 9, 1984 - November 8, 1984
4.	Completion and connection of two RMW gas control wells and one previous pumping test well into the existing system	October 9, 1984 - November 8, 1984
5.	Testing of Phase II, Part A	November 8, 1984 - February 22, 1985
6.	Electrical problem - system shut down	November 12 and 13, 1984
7.	Intermittent boiler use and operation of landfill gas	November 5, 1984 - January 17, 1985
8.	System operated every day	January 21, 1985 - February 22, 1985
9.	Test terminated	February 22, 1985

- changeover of the pumping system to provide a flow rate on the order of 248 L/s;
- gas well monitoring and balancing at the increased flow rate; and
- completion and connection of two gas control wells, and a previous pumping test well in the western corner of the site, into the existing pumping system (this work was conducted by CRA under a separate work agreement with the Region).

Figure 16 shows the typical well installation detail. Table 5 provides the installation details for each newly installed well.

To avoid the odour and scattered refuse problems encountered during Phase I construction, the distance the contractor was allowed to excavate ahead of the pipe installation was restricted while excavating in refuse. Also, the contractor was not allowed to leave any uncompleted or open trench areas or any on-site refuse piles at the end of the working day.

TABLE 5 NEW WELL INSTALLATION DETAILS

Well Number	Depth (m)	Length Of Screen (m)	Seal Thickness (m)	Length of Slide Mechanism (m)
23	13.72	6.1	2.44	1.22
25	10.36	3.05	1.68	1.22
26	8.23	3.05	1.52	1.52
27	19.35	6.1	3.66	1.37
28	18.59	6.1	2.74	1.22
29	16.76	6.1	1.98	1.37
30	19.20	6.1	4.6	1.22
31	16.76	4.6	7.32*	1.22
32	14.48	6.1	1.52	1.22

* perched water zone sealed off

5.1.1 Phase II, Part A - Testing Results. As outlined in the September 13, 1984, DRECT proposal, the complete well system was to be pump tested at a rate of 248 L/s for a minimum of three months. This rate was sufficient to fuel both plant boilers on "high fire" providing that the gas contained 40% methane by volume. During the pumping test, the boiler operating on landfill gas was only used for kiln drying and was not required to meet daily heating requirements. During Phase II, Part B, the pumping system was to be modified to provide a system capable of satisfying all Bestpipe's space heating requirements.

The testing of Phase II, Part A was conducted between November 8, 1984, and February 22, 1985. During the test, methane concentrations at the pumphouse were recorded by both the Region and CRA. Throughout the test, well field adjustments were made in an attempt to maintain a methane concentration of 40% by volume. Table 6 presents all monitoring results and the dates of all well adjustments made during the pumping test period. The measured methane concentrations are plotted against time for the test period (Figure 17).

Due to an electrical problem at the pumphouse, the system was shut down on November 12 and 13, 1984. This shut down was not related to the use of landfill gas.

TABLE 6 KITCHENER LANDFILL GAS TEST SUMMARY

Date	Pumphouse Conc. (% CH_4)	Comments
Nov. 5/84	45	- test start-up, initial readings
Nov. 8/84	50	- wells adjusted
Nov. 16/84	40	
Nov. 19/84	47	- wells adjusted
Nov. 26/84	56	
Nov. 27/84	40	- wells adjusted
Nov. 30/84	39	
Dec. 2/84	47	
Dec. 6/84	37	
Dec. 10/84	39	- wells adjusted
Dec. 13/84	36	
Dec. 17/84	43	
Dec. 20/84	36	
Dec. 21/84	41	
Dec. 24/84	48	
Dec. 27/84	48	
Dec. 31/84	51	
Jan. 2/85	49	
Jan. 4/85	49	
Jan. 7/85	45	
Jan. 10/85	37	
Jan. 11/85	50	- wells adjusted
Jan. 14/85	49	
Jan. 17/85	44	
Jan. 21/85	53	
Jan. 21/85	52	
Jan. 22/85	44	
Jan. 22/85	45	
Jan. 23/85	48	
Jan. 23/85	41	

TABLE 6 KITCHENER LANDFILL GAS TEST SUMMARY (Cont'd)

Date	Pumphouse Conc. (% CH_4)	Comments
Jan. 24/85	44	
Jan. 24/85	39	
Jan. 25/85	38	
Jan. 25/85	37	
Jan. 28/85	34	
Jan. 29/85	37	
Jan. 31/85	40	- wells adjusted
Feb. 1/85	35	
Feb. 4/85	36	- wells adjusted
Feb. 5/85	41	
Feb. 6/85	35	
Feb. 6/85	35	
Feb. 7/85	33	
Feb. 7/85	34	- wells adjusted
Feb. 8/85	33	
Feb. 11/85	39	
Feb. 11/85	35	
Feb. 13/85	41	
Feb. 14/85	33	
Feb. 15/85	32	
Feb. 19/85	36	
Feb. 20/85	30	
Feb. 21/85	32	- wells adjusted
Feb. 22/85	34	- wells adjusted
	END OF TEST	
Feb. 28/85	44	- pump flow rate lowered to one boiler

As seen in Table 6 and Figure 17, the methane concentrations varied considerably over the test period. Between November 5, 1984, and January 17, 1985, the methane concentrations varied from 56% to 37%. There were several days when the boiler could not operate on landfill gas, due to low concentrations. During these times the gas collection system was shut down.

To obtain valid results for the remainder of the test, the system was operated every day from January 21 to February 22, 1985, by the Region regardless of Bestpipe's usage. During this period, methane concentrations continued to fluctuate. Concentrations ranged from a high of 53% to a low of 30%, but showed a steady decrease with time (Figure 17). The test was terminated on February 22, 1985, as it became apparent that a concentration of 40% could not be maintained at the higher flow rate without constant gas well adjustments. It was recommended by CRA, therefore, that Phase II, Part B of the project not proceed. This recommendation was based on:

1) a concentration of 40% combustible gas by volume could not be maintained without constant field adjustments; and

2) close to or above the current site gas production rate would be required to fuel both boilers.

Even though the second boiler was not placed on line, the authorities were pleased with the system as it helps to control landfill gas migration from the existing landfill site and generates revenue from the sale of landfill gas.

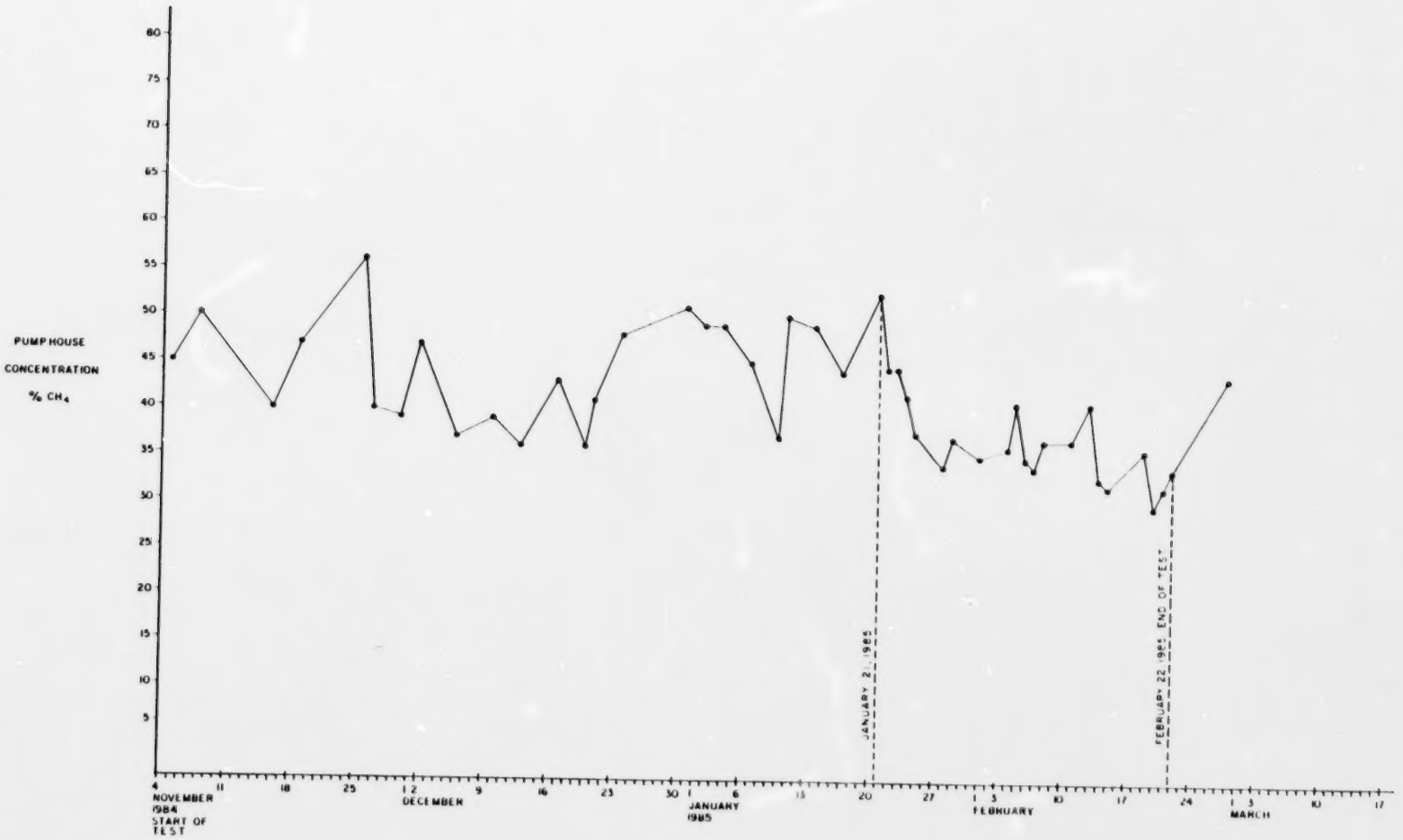


FIGURE 17 PHASE II - TEST GAS CONCENTRATION VERSUS TIME

6 PRESENT SYSTEM OPERATIONAL STATUS

Since February 22, 1985, the landfill gas system has been operating smoothly and supplying sufficient landfill gas to Bestpipe to fuel one boiler. The flow rate is currently 118 L/s. Methane concentrations from the end of the Phase II, Part A test to the present have been monitored by the Region. Table 7 presents the monthly monitoring results CRA received from the Region up to September 30, 1985.

Methane concentrations since the end of the Phase II, Part A test have varied by 34% to 53%, but have maintained a monthly average of over 40%.

Oxygen concentrations have remained low, averaging less than 1%, which indicates that there is very little intrusion of atmospheric air to the system.

As Table 7 indicates, gas concentrations since February 22, 1985, have generally stabilized and no longer show the downward trend observed during the Phase II, Part A pumping test. At present, the Region and Bestpipe are satisfied with the reliability and operation of the system.

6.1 Operational Difficulties

At this time, most of the operational difficulties encountered during Phase I have been overcome and the system is operating smoothly. The gas collection system, as designed, made use of an air-cooled aftercooler. This system proved effective only above freezing temperatures. In the winter, the unit would freeze, necessitating its bypass during system operation. Due to the corrosive nature of the condensate within the landfill gas, the air-cooled aftercooler tubing eventually corroded causing leaks. The present aftercooler is, therefore, inoperative.

At the present time, the aftercooler has been taken out of service and the system is operating without water removal after the blower. The frequency of draining the positive pressure drain traps has been increased to once per month. The system has been operating satisfactorily in this state with no significant increases in the amount of water that is drained from the positive pressure trap.

No decision on the replacement of the aftercooler has been made by the Region at this point in time.

TABLE 7 MONTHLY MONITORING OF GAS UTILIZATION SYSTEM

Date M/D/Y	% Methane	Discharge Pressure (kPa)	Oxygen (%)	BP Meter Reading (m^3)	System Status
05/03/85	56.0	41.4	0.3		
05/06/85	58.0	41.4	0.5		
05/09/85	50.0	41.4	1.0		
05/15/85	42.0	41.4	0.6		
05/17/85	46.0	42.1	0.3		
05/21/85	46.0	42.1	1.2		
05/23/85	42.0	43.4	1.0		
05/23/85	42.0	40.0	1.0		
05/27/85	40.0	36.5	1.0		
05/30/85	41.0	36.5	1.0		
06/05/85	40.0	37.9	1.0		system okay
06/11/85	53.0	38.6	0.8	745963	system okay
06/11/85	53.0	38.6	0.8	745963	system okay
06/12/85	50.0	37.2	1.1	745963	system okay
06/12/85	50.0	37.2	1.1	745963	system okay
06/14/85	42.0	37.9	1.2	748589	system okay
06/14/85	42.0	37.9	1.2	748589	system okay
06/17/85	44.0	38.6	0.9	753069	system okay
06/17/85	44.0	38.6	0.9	753069	system okay
06/18/85	47.0	38.6	0.8	765271	system okay
06/18/85	47.0	38.6	0.8	755271	system okay
06/19/85	47.0	38.6	1.2	757778	system okay, power failure alarm
06/19/85	47.0	38.6	1.2	757778	alarm due to power failure
06/20/85	47.0	38.6	0.8	760154	system okay
06/20/85	47.0	38.6	0.8	760154	system okay
06/21/85	37.0	38.6	1.0	762576	system okay
06/22/85	37.0	38.6	1.0	762576	system okay
06/24/85	38.0	38.6	0.9	764714	system okay
06/24/85	38.0	38.6	0.9	764714	system okay
06/25/85	40.0	38.6	1.0	767194	system okay, some oil seepage pump
06/25/85	40.0	38.6	1.0	767194	could be some oil seepage
06/26/85	35.0	38.6	1.0	769690	system okay, no further oil seepage
06/26/85	35.0	38.6	1.0	769690	no further seepage
06/28/85	38.0	40.7	1.2	774602	no apparent oil seepage
07/02/85	47.0	40.0	0.8	777190	system okay
07/04/85	37.0	40.6	1.0	781232	system okay
07/05/85	40.0	40.0	1.0	783266	system okay
07/10/85	44.0	40.0	1.0	789470	system okay

TABLE 7 MONTHLY MONITORING OF GAS UTILIZATION SYSTEM (Cont'd)

Date M/D/Y	% Methane	Discharge Pressure (kPa)	Oxygen (%)	BP Meter Reading (m^3)	System Status
07/11/85	37.0	38.6	1.3	791477	system okay
07/12/85	40.0	39.3	1.3	793782	system okay
07/15/85	49.0	38.6	0.8	795833	system okay
07/16/85	38.0	37.9	0.9	797817	system okay
07/17/85	37.0	38.6	0.8	800140	system okay
07/18/85	42.0	39.3	1.1	802225	system okay
07/19/85	40.0	39.3	1.2	804623	system okay
07/22/85	32.0	38.6	0.9	807298	system okay
07/23/85	38.0	38.6	0.8	809601	system okay
07/24/85	35.0	38.6	1.3	812011	system okay
07/29/85	34.0	40.0	0.5	818598	system okay
07/30/85	38.0	38.6	0.4	820822	system okay
07/31/85	34.0	40.0	0.3	822991	system okay
08/01/85	43.0	40.0	0.8	825127	system okay
08/02/85	43.0	40.0	0.8	825127	system okay
08/06/85	47.0	40.0	0.7	829965	system okay
08/07/85	40.	37.9	0.4	831928	system okay
08/08/85	41.0	38.6	0.5	834161	system okay
08/08/85	38.0	38.6	0.5	836414	system okay
08/12/85	46.0	38.6	0.4	838776	system okay
08/13/85	38.0	38.6	0.3	840579	system okay
08/14/85	39.0	38.6	0.2	842618	system okay
08/16/85	37.0	38.6	0.5	846988	water lines flushed, system okay
08/19/85	43.0	37.9	0.2	849347	system okay
08/20/85	42.0	38.6	0.3	851424	system okay
08/22/85	37.0	39.3	0.3	855482	system okay
08/28/85	39.0	39.3	0.9	863775	system okay
08/30/85	44.0	37.9	0.5	867554	system okay

7 PROJECT ECONOMICS

7.1 Capital and Operating Costs

7.1.1 Capital Costs. Tables 8 to 10 present the capital costs for the various phases of the total landfill gas utilization project. Table 8 presents costs for the original Phase I and Phase I - Optimization work. Table 9 presents costs for the Phase II, Part A costs, and Table 10 presents a summary of capital costs for the entire project. Where applicable, the tables list unit cost per item for future budget approximations. Table 10 also lists the percentage of total costs allocated to various major aspects of the project work.

TABLE 8 TOTAL COST* PHASE I AND PHASE I - OPTIMIZATION

Item	Cost	Approximate Unit Cost
1) Gas Well Construction - 23 wells (22 wells + 1 test well)	$ 55 000.00	$2 500.00/well
2) Gas Line Construction (11 000 ft, of pipe)	215 500.00	$20.00/ft
3) Pumphouse/Mechanical Equipment	121 000.00	
4) Boiler Conversion/Metering Equipment	30 500.00	
5) Engineering Design, System Monitoring Testing, Misc. Work to Bring System On-Line	71 000.00	
TOTAL	$493 000.00	

* cost to nearest $500.00

TABLE 9 TOTAL COST* PHASE II, PART A SYSTEM

Item	Cost	Approximate Unit Cost
1) Gas Well Construction - 13 wells (9 constructed, 4 existing)	$20 500.00	$1 600/well
2) Gas Line Construction and Connections (2000 ft, of pipe)	29 500.00	$15/ft
3) Engineering Design, System Monitoring, Testing, Reporting	18 500.00	
TOTAL	$68 500.00	

* cost to nearest $500.00

TABLE 10 TOTAL COST SUMMARY COMPLETE PROJECT, PHASES I, II*

Item		Cost	% of Total Cost
1)	Gas Well Construction - 33 wells (22 Phase I + 1 test well; 9 Phase II + 1 test well)	$75 500.00	13
2)	Gas Line Construction	245 000.00	44
3)	Mechanical System (including pumphouse, boiler conversions, etc.)	151 500.00	27
4)	Engineering Design, Testing, Monitoring, Misc. Work to Bring to Operational Status	89 500.00	16
	TOTAL	$561 500.00	100

* cost to nearest $500.00

7.1.2 Operational Costs. Table 11 lists the actual operational costs for 1984 as supplied by the Region. These costs would be representative of anticipated 1985 operational costs as the second boiler was not connected to the landfill gas utilization system.

7.2 Funding

A number of government agencies and private companies funded the capital costs of the project to varying degrees. The funding groups include: the Regional Municipality of Waterloo; Bestpipe (a Division of Lake Ontario Cement); Environment Canada (DRECT grant); the Ontario Ministry of Energy; and Conestoga-Rovers & Associates Limited (Table 12).

7.3 Contractual Agreement and Revenues

7.3.1 Contractual Agreements. The Region negotiated a selling price with Bestpipe for the landfill gas based upon the preliminary cost estimates. This contract was based on the criteria that the Region would have a simple return on investment of approximately 5 years (capital cost minus DRECT grant). The price agreed to was $47.67/1000 m^3 for gas at 13.13 MJ/m^3 with an allowance for variations in price as a function of methane concentration. This price is equivalent to approximately 37.5 MJ/m^3 of natural gas which was the selling price of natural gas in the Kitchener area in late 1981. This price for

TABLE 11 ACTUAL 1984 OPERATIONAL COSTS*

Item	Actual 1984
1) Materials and Supplies	$ 156.00
2) Maintenance and Repairs	4 833.00
3) Utilities	1 655.00
4) Services	736.00
5) Communication Costs	331.00
6) Travel Expenses	347.00
7) Inter-departmental Charges	3 819.00
	$11 877.00

* Operational Costs for 1985 Totalled $9 000.00

TABLE 12 AGENCY FUNDING*

Agency/Company	Approximate Funding Amount (nearest $100.00)	% of Total Project
Regional Municipality of Waterloo	$217 700.00	39
Bestpipe (a division of Lake Ontario Cement)	40 200.00	7
Environment Canada	193 600.00	35
Ontario Ministry of Energy	70 000.00	12
Conestoga-Rovers & Associates Limited	40 000.00	7
TOTAL	$561 500.00	100

* funding cost quoted to nearest $100.00

landfill gas was to become effective when the operation went on line in 1982 and would apply until July 1983 when annual 10% increases in the landfill gas price were expected to occur. The contract was set for a five-year period, after which time the agreement would be renegotiated.

It was recognized by Bestpipe that the selling price for the landfill gas had an initial economic advantage over natural gas and that this would improve further with time. Assuming the price increases in natural gas would be greater than 10% per year.

Due to the initial delay in placing the system into full time operation, the contract took effect in 1983, at the initial selling price described previously. This gave Bestpipe a further price advantage in the order of 30% below current equivalent natural gas prices in Kitchener. However, this advantage is now anticipated to decrease as natural gas price increases have only been in the order of 5% to 10% over the last year, with no anticipated increase in cost for 1985, in the Kitchener area. Currently, Bestpipe estimates they are saving about 15% to 20% by using the landfill gas in place of natural gas for the single boiler.

7.3.2 Revenues. Table 13 presents the landfill gas quantities consumed by Bestpipe and the Region's gross revenue from sales fo this landfill gas for 1984 and 1985.

Both years had gas sales interruptions due to system monitoring and testing, and therefore 1986 sales have been projected based on 1984 and 1985 volumes to be about 600 000 m^3 at 45% methane by volume. This would be equivalent to approximately 269 000 m^3 of natural gas.

7.4 Economic Analysis

7.4.1 Landfill Gas Supply Cost. The cost of supplying landfill gas to Bestpipe has been calculated to be \$0.384/m^3 based on:

1) a capital cost of \$561 500 amortized over 10 years at 10% interest rate equivalent to \$91 480/year;
2) an operating cost of \$12 000/year as given in Table 13; and
3) a yearly gas supply equivalent to 269 000 m^3.

The northern well field presently supplies the bulk of landfill gas for utilization. The southern well field is used more for landfill gas control purposes than for utilization by the Region. Therefore, in terms of utilization, the southern well field is no longer used and if its cost (\$120 000) is subtracted from the total project cost, the actual cost of landfill gas supply is approximately \$0.312/m^3 based on:

1) a capital cost of \$441 500 amortized over 10 years at 10% interest rate equivalent to \$71 900/year;
2) an operating cost of \$12 000/year as given in Table 13; and
3) a yearly gas supply equivalent to 269 040 m^3 of natural gas.

TABLE 13 LANDFILL GAS QUANTITY AND SALES REVENUE

Year	Quantity* (m^3)	Avg. % Combustible (Gas)	Total Sales Revenue
1984	501 302	46%	$32 801.45
1985	467 783	45%	$31 215.56

* In both years shutdowns in the heavy usage winter season (Jan.-Mar.) occurred due to poor gas concentration (1984), and testing (1985) - Region estimates total sales for 1986 of minimum $45 000.00.

The current Kitchener Public Utilities rate for industrial users is about $5.50 to $6.50/$10^3$ ft^3 ($0.19 to $0.23/$m^3$). The present actual cost of supply of landfill gas to the single boiler at Bestpipe is 50% higher than current rates. Not enough landfill gas can be produced or utilized with a single boiler at Bestpipe to make the project viable on an economic basis alone.

If the supply of landfill gas was sufficient to permit conversion of the second boiler at Bestpipe, the landfill gas supply cost (equivalent to natural gas) would have been reduced to approximately $0.162/$m^3$ based on:

1) a total projected capital cost (complete system) of $696 000 amortized over 10 years at 10% interest rate, equivalent to $113 000/year;
2) an operational cost of $15 000/year; and
3) a yearly gas supply of Bestpipe Plant of 792 960 m^3 (based on Bestpipe previous and present natural gas consumption figures for both boilers).

This cost is 24% lower than equivalent current Kitchener natural gas rates. This demonstrates that if enough landfill gas is required and is available, "as is" utilization of landfill gas to nearby industrial facilities is economically viable.

The Regional landfill gas supply cost at present is approximately $0.18/$m^3$ because of subsidies from other sources (Table 12). This gas supply cost figure is based on:

1) a capital cost of $217 700 amortized over 10 years at 10% interest rate equivalent to $35 400/year;
2) an operating cost of $12 000/year; and
3) a yearly gas supply equivalent to 37 500 m^3 of natural gas.

This cost is comparable to the present cost of natural gas in Kitchener (1986).

National economic viability would depend on natural gas costs in other areas of the country. Table 14 presents current natural gas rates in various provinces for larger industrial consumers.

In general, landfill gas utilization on an "as is" basis should be economically viable when compared to natural gas costs for the eastern provinces and Ontario and Quebec. The western provinces are less economical when compared to their current natural gas rates for gas supply quantities as outlined in the Kitchener project. With larger quantities of "as is" gas utilized and increases in natural gas rates, landfill gas usage in British Columbia and Manitoba may be marginally economically viable. It is not likely that "as is" landfill gas usage in Alberta and Saskatchewan will be economically viable in the near future.

It should be noted that trends in Ontario dictate that odour control systems be installed for newly approved landfill facilities. The odour control systems can be designed so that the landfill gas collected can also be utilized. The revenue generated from utilization can be used to offset the cost of odour control, and utilization will become more economically viable when it is considered that landfill gas collection facilities for odour control must be installed whether or not the landfill gas is utilized.

TABLE 14 SELECTED PROVINCIAL AVERAGE NATURAL GAS RATES* (1985)

Province	Average Industrial Rate ($/m^3)	($/10^{3}ft^3)
Ontario	0.155	4.39
Quebec	0.170	4.82
Manitoba	0.127	3.60
Saskatchewan	0.113	3.20
Alberta	0.075	2.12
British Columbia	0.127	3.60
New Brunswick**	0.286	8.10

* Canadian Gas Rates, Canadian Gas Association
** New Brunswick rate is a commercial rate, no industrial rate given

8 ENERGY SAVINGS AND ENVIRONMENTAL BENEFITS

The utilization of landfill gas as an alternate fuel source can save non-renewable energy resources and have positive environmental benefits for presently operating or closed landfill sites.

8.1 Energy Savings

8.1.1 Local Savings. The present landfill gas utilization system saves approximately 254 880 m^3 of natural gas annually. This is equivalent to approximately 244.8 m^3/yr of oil, or enough energy to heat 90 residential homes per year (based on a 1600 ft^2 home in Kitchener-Waterloo built to 1985 building standards).

8.1.2 National Savings. It is difficult to estimate the potential energy savings from utilization of landfill gas on a national basis.

CRA estimates that at present, there are approximately twenty landfill sites in Canada with a minimum of one million tonnes of refuse in place. This is the minimum tonnage required to make landfill gas recovery technically and economically feasible assuming:

1) each of the twenty sites has one million tonnes available for gas utilization;
2) a large user is nearby, and can utilize all landfill gas supplied; and
3) a landfill gas recovery rate of 6.29×10^{-3} $m^3/kg \cdot yr$ at 40% combustible gas by volume (landfill gas available for use would be equivalent to 4.5×10^7 m^3 of natural gas).

Landfill gas could potentially displace 0.1% of the total industrial end use energy consumed in Canada per year. (Based on data supplied from Statistics Canada Catalogue No. 57-003, "Quarterly Report on Energy Supply and Demand in Canada). This would also be equivalent to approximately 43 562.5 m^3 of oil.

8.2 Environmental Benefits

Collection of landfill gas for utilization as a fuel source can have overall environmental benefits regarding landfills and landfill operation.

By collecting the landfill gas the amount of gas available for free venting through the landfill cover into the atmosphere is reduced. This can help to reduce odours sometimes associated with landfill operation. Collecting the gas also reduces the amount of gas available for migration in soils from the landfill site. This migration can potentially create explosive conditions in any enclosed structures located near to the site.

At the Kitchener landfill, migration of landfill gas from the site had affected nearby residences and a school located adjacent to landfill boundaries. The effect of the collection system on gas migration has been monitored by CRA, and has been found to be effective in controlling migration of landfill gas from the site. This was a definite asset to the Region which, to date, has spent about $700 000 to control landfill gas migration.

9 RELATED STUDIES

9.1 Evaluation of Landfill Gas Recovery

There are two studies under separate funding that have been conducted in relation to the Kitchener Landfill Gas Utilization Project:

1) the "Evaluation of Landfill Gas Recovery System as a Migration Control System", funded by the Ontario Ministry of the Environment; and
2) the boiler tube corrosion testing, funded by Ontario Ministry of Energy.

9.2 Evaluation of Landfill Gas Recovery System as a Migration Control System

This project, which was completed in March 1983, evaluated the effectiveness of the gas recovery system as a migration control system. As discussed earlier, the Region has had off-site gas migration problems at the landfill and believed the recovery system would help alleviate these problems.

The study results indicated that the recovery system is effective in the control of gas migration. The results of this study were presented directly to the Ontario Ministry of the Environment in the report entitled "Evaluation of a Landfill Gas Recovery System to Control Gas Migration", prepared by Conestoga-Rovers & Associates Limited, March 1983.

9.3 Boiler Tube Corrosion Testing Study

The boiler tube corrosion testing study was designed to record the corrosion effects of the landfill gas on the fire tubes within the boiler. Initially, fourteen boiler tubes within the boiler were replaced. Seven tubes were replaced from the second pass of the boiler where high temperature corrosion could take place. The remaining seven tubes were replaced in the fourth pass of the boiler where low temperature or wet corrosion is likely to occur.

These tubes were removed and examined for corrosion on several occasions during the operation of the gas utilization system. All scheduled tube removal events have been completed and CRA is presently awaiting the corrosion report from the University of Waterloo. In general, no significant corrosion has been detected on the boiler tubes examined. Some scale has developed on the burner pot; however, it is not significant and its relationship to landfill gas has not yet been determined.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made in conjunction with the text of this report:

1) The utilization of landfill gas on an "as is" basis is technically viable in Canada.

2) Landfill gas usage on an "as is" basis can be economically viable at present in Ontario, depending on quantities produced and marketable volumes. Landfill gas utilization systems will become even more economically viable when one considers that most new landfill sites will have gas collection systems for odour control and gas utilization can use these collection systems.

3) Energy savings from the Kitchener landfill gas utilization project amount to approximately 244.8 m^3/yr of oil (1540 barrels), or enough fuel to heat 90 residential homes.

4) On a national basis, use of landfill gas in an "as is" state from existing landfill facilities, could conservatively displace about 0.1% of current national industrial end use energy requirement (or, 43562.5 m^3/yr (274 000 barrels) of oil).

5) "As is" landfill gas usage is not likely to be economically viable in Alberta or Saskatchewan in the near future due to comparatively low natural gas prices in these areas.

6) Environmental benefits can be obtained from collecting landfill gas from existing landfills for utilization. These benefits would include reduction of odours and reduction of landfill gas migration.

7) Landfill gas collection and utilization systems can also be designed to effectively control landfill gas migration on existing sites.

8) It is recommended that, if future sites are to consider landfill gas utilization systems, site specific studies be undertaken to determine amount of gas available and the potential markets, prior to proceeding with the project.